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CONTENTS

IRON AND STEEL INSTITUTE PAPERS

"The Protective Action of Sprayed Aluminium Coatings on Steel" *by G. Tolley* 377

"Open-Hearth Furnace Models"
Pt. I—"Flow Patterns in Ducts" *by J. H. Chesters and A. R. Philip* 385
Pt. II—"Flow Visualization and Photography" *by R. S. Howes and A. R. Philip* 392
Pt. III—"Flow Patterns in Model Furnaces" *by I. M. D. Halliday and A. R. Philip* 401

Historical Note No. 12—
"The Little Smith of Nottingham" *by H. R. Schubert* 416

DISCUSSION ON PAPERS

Autumn General Meeting, 1948—
Discussion on Open-Hearth Instrumentation 417
Discussion on Slag Basicity 422
Discussion on Magnetic Study of Stainless Steel Wires 424
Discussion on Hardenability and Isothermal Transformation 427
Discussion on Moisture in Producer Gas 429
Discussion on Fatigue Tests on Crankshaft Steels 432

BRITISH IRON AND STEEL RESEARCH ASSOCIATION

"The Mechanism of Freezing of Horizontal Steel Castings" *by the Melting and Metallurgical Committee* 437

"Observations at the Stockline in a Driving Blast-Furnace" *by E. W. Voice* ... 450

"Experiments on the Gas and Fluid Flow in a Side-Blown Converter Model" *by M. P. Newby* 452

"Experiments on Gaseous Mixing in Open-Hearth Furnace Models" *by R. D. Collins and J. D. Tyler* 457

IRON and STEELWORKS ENGINEERING

Discussion on Specialized Rolling Stock for Iron and Steel Works 467

NEWS

Iron and Steel Institute ... 475
News of Members 475
Contributors to the Journal 475
Iron and Steel Engineers Group 476
Affiliated Local Societies ... 476
Institute of Metals 476
News of Science and Industry 477
Memoirs 477
Diary 478
Translations 478

ABSTRACTS and BOOK NOTICES

Contents 479
Abstracts 479-493
Book Notices 493
New Publications 496

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JAMES EDGAR HURST, F.I.M., D.Met., J.P.

DR. JAMES EDGAR HURST, Managing Director of Bradley and Foster, Ltd., and Director of Research to The Staveley Coal and Iron Co., Ltd., is well-known for his work in the development of the centrifugal casting process, particularly in its application to special high-duty cast irons.

After serving as Assistant Chemist at the locomotive works of Messrs. Beyer, Peacock and Co., Ltd., and as Chief Chemist and Metallurgist of Richard Hornsby and Sons, Ltd., Dr. Hurst joined the staff of D. Napier and Sons, Ltd., during the First World War, in the position of Chief Chemist and Metallurgist. In 1918 and 1919 he was Editor of the Foundry Trade Journal. In 1925 he joined the firm of Messrs. Bradley and Foster, Ltd., and was for many years their Technical Director. In 1945 he was appointed Director of Research to The Staveley Coal and Iron Co., Ltd., and was then responsible for the co-ordination of the chemical and metallurgical research of the Staveley-Bradley Foster research group. Dr. Hurst was appointed Managing Director of Messrs. Bradley and Foster, Ltd., of Bradleys (Concrete), Ltd., and of Bradleys (Darlaston), Ltd., in March, 1949. He also became Chairman and Managing Director of Arblaster and Co., Ltd., and Ernest Graham and Co., Ltd. He is Technical Director of the Birmingham Chemical Co., Ltd.

A long association with the Institute of British Foundrymen commenced with his election as a member in 1914, and he was elected President in 1935. He is also Past-President of the Sheffield Branch of the Institute. In 1932 he was awarded the Oliver Stubbs Gold Medal for his contribution to the metallurgy of cast iron, and in 1938 he received the E. J. Fox Gold Medal. Results of some of his investigations on cast irons were presented to the Institute of British Foundrymen in a series of papers, commencing in 1930. Dr. Hurst is also a Past-President of the Staffordshire Iron and Steel Institute, and a member of The Institution of Mechanical Engineers.

Apart from the technical field, Dr. Hurst has also been prominent in local affairs. He has been a Justice of the Peace for the City of Lichfield since 1942, becoming Sheriff of the City and County in 1945. He is President of the National Trades Technical Societies ; Chairman of the Johnson Society of Lichfield ; Freeman of the Worshipful Company of Smiths, Lichfield ; Liveryman of the Worshipful Company of Founders, and a Freeman of the City of London.

Dr. Hurst became a member of The Iron and Steel Institute in 1916, and has published many papers in the Journal. He was awarded a Carnegie Research Scholarship in 1917. As Representative of the Institution of Metallurgists, he is an Honorary Member of Council of The Iron and Steel Institute.

Vandyk

J. E. Hurst, F.I.M., D.Met., J.P.

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IRON AND STEEL
INSTITUTE PAPERS

PLANT DESIGN · MANUFACTURE · RESEARCH · DEVELOPMENT

The Protective Action of Sprayed Aluminium Coatings on Steel

By G. Tolley, M.Sc., A.R.I.C.

SYNOPSIS

The galvanic behaviour of steel/sprayed-aluminium couples has been investigated in various solutions during one week's immersion. Only in solutions of pH less than 3, and in solutions containing a concentration of aluminium ions greater than $1 \cdot 9 \times 10^{-4}$ *M*, is sprayed aluminium initially anodic to steel. The corrosion processes affecting the changes in electrode potential during immersion are discussed in relation to observed early rust-staining of sprayed-aluminium coatings on steel. The effect of aluminium sulphate on the corrosion of steel has been investigated. This substance is an accelerator of corrosion in several solutions tested, yet, by the formation of aluminium hydroxide, it considerably delays the appearance of brown iron rust on the surface of the immersed steel.

Introduction

Coatings of sprayed aluminium on steel provide an excellent means of protecting iron and steel against corrosion under widely differing conditions of exposure, and the process has been in commercial use for several years. The investigations of Britton and Evans,[1] Sutton and Braithwaite,[2] and Hudson and Banfield[3] among others, have shown the protective value of such coatings. The actual extent of protection afforded by aluminium on steel has not been clearly defined, and it is still not clear under what conditions aluminium affords electrochemical protection to steel. The present work was undertaken to clarify the electrochemical relationships of aluminium and steel, and to investigate the mechanism of the protective action of aluminium coatings on steel. The scope of the work has been limited to an investigation into the causes and prevention of early rust-staining of aluminium coatings on steel.

Many opinions have been expressed concerning the relative galvanic action between aluminium and steel, but no clear decision emerges from a study of the literature, except the realization by most workers of the importance of exposure conditions. Generalized statements that aluminium is anodic to steel[4, 5] have little value in the face of experimental evidence to the contrary. Hippensteel found that aluminium/iron couples exposed in humid sea-coast air suffered accelerated attack of both metals, and in milder atmospheres no galvanic action was observed.[6] Bengough and Hudson, and Edwards and Taylor observed that under some conditions aluminium is anodic to steel.[7, 8] Evans found that aluminium is normally anodic to steel in aqueous solutions, but under certain conditions steel becomes anodic.[9] The same worker also found that a sprayed aluminium coating gave no sacrificial protection to steel in hard water, yet it was protective in a salt solution.[10] Cazaud has obtained results showing that aluminium is anodic to iron in sea water.[11] Under conditions of long-term atmospheric exposure in widely varied localities, there is little doubt that aluminium provides sacrificial protection to steel.

RUST-STAINING OF ALUMINIUM COATINGS

Although the protective value of sprayed aluminium has been established, it is known that considerable rust-staining of this type of coating may occur in the early stages of atmospheric exposure. Nevertheless, it is usual to find that the thickness and texture of the coating are satisfactory, and no permanent damage or loss in protective properties seems to be caused. The stains usually disappear slowly until, after a few months' further weathering, little trace of the early rusting remains. The protective value of the coatings over long periods would, therefore, probably be unaffected, the only real difficulty lying in the appearance of the stained article, suggesting that the coating is non-protective. Britton and Evans observed that rust-stains appeared on aluminium-coated steel in

Manuscript received 18th November, 1948.
Mr. Tolley is Chief Chemist to Metallisation, Ltd.

the early stages of exposure, but these soon disappeared, leaving a dark grey stain.[1] Evans has suggested that this stain is redeposited iron.[12]

Preliminary exposure tests showed that rust-staining of aluminium-sprayed steel could be obtained in the first few hours of exposure to urban or industrial atmospheres. In one case a mild-steel sheet, coated with 3 mil. of aluminium, was exposed to a mild urban atmosphere within 8 hr. of coating. Overnight there was a frost followed by a quick thaw. The sheet showed rust-stains as soon as the thaw was complete, so that water released from the frost had only a few hours in which to cause rusting. The rust-stains did not increase with further exposure, and within several weeks there were signs that they were disappearing. Similar examples suggest that the initial exposure conditions are of importance in the behaviour of the coating. It is not necessary for excessively corrosive conditions to occur in the early stages, and there is some evidence to show that acid waters tend to suppress the appearance of rust-stains.

A mild-steel plate, coated with 3 mil of aluminium, was placed horizontally in a dish exposed to an industrial atmosphere, and was barely covered with distilled water. Rust-stains showed within 16 hr., although no further signs of rusting occurred, and after four days the stains showed signs of disappearing. $M/200$ sulphuric acid, when used instead of distilled water under the same conditions, gave no signs of rust-staining of the coating.

Because of the influence of the corroding medium, preliminary work was carried out on the behaviour of steel/sprayed-aluminium couples immersed in various solutions.

BEHAVIOUR OF STEEL/SPRAYED-ALUMINIUM COUPLES IMMERSED IN VARIOUS SOLUTIONS

Couples of $\frac{1}{8}$-in. dia. wire were set up in test tubes and connected through brass terminals. Bare steel (0·4% C) and 99·5% Al, sprayed with aluminium of the same purity, were used. After five days' immersion the couples were removed and the change in weight, after removing corrosion products, was determined for each wire. It was apparent that in a wide range of solutions aluminium was cathodic to steel. The following solutions were tested : (i) Distilled water ; (ii) sodium chloride $M/1000$ to M ; (iii) ammonium sulphate $M/4000$ to $M/200$; and (iv) sulphuric acid $M/4000$ to $M/200$. In all these solutions aluminium was anodic to steel only in sulphuric acid of concentration greater than $M/2000$, and in the more concentrated sodium chloride solutions. It seems, therefore, that only in very acid rain waters and in sea water is aluminium likely to be anodic to steel.

Results obtained in aluminium sulphate solutions showed that, in solutions of concentration greater than about 4×10^{-4} M, aluminium was anodic to steel, and furthermore, that the addition of small quantities of aluminium sulphate to those solutions in which aluminium was cathodic to steel resulted in an apparent reversal of potential.

This preliminary series of tests could give only qualitative results, which were not very reliable, because of the complicating factors of reactions at the water-line. These studies were extended, therefore, by measuring the potential difference between steel and aluminium plates immersed in various solutions. The variation of potential with time is of much greater importance in the present investigation than the initial or final value, and, although the mere fact that aluminium is anodic to steel does not mean that sacrificial protection will be given, a knowledge of the variation in the difference of potential will provide a good basis for discussion of the actual progress of corrosion.

Experimental Procedure

As the solution potential of aluminium varies considerably with surface condition, particularly in regard to the nature and thickness of the oxide film,[13] it is very necessary to ensure that the potential of sprayed aluminium is actually obtained. The ideal electrode for this purpose would be a rod or sheet composed entirely of sprayed aluminium ; such specimens are, however, very difficult to prepare, and so a composite specimen was built up by spraying a coating of aluminium, 10 mil. thick, on to a sheet of 20-gauge aluminium. The aluminium sheet was of 99·5% purity, and the composition of the wire used for spraying was : Si 0·25%, Fe 0·25%, Cu 0·005%, Mn 0·004%, Zn 0·007%, Al 99·48% (by difference). The steel electrodes were of bright steel (0·18% C) ; they were polished with No. 0000 emery and degreased with carbon tetrachloride before use. The specimens were 5 cm. × 7 cm. × 20 gauge, with a $\frac{3}{16}$-in. suspension hole drilled centrally, $\frac{5}{16}$ in. from the top edge. Each couple was held rigidly in a synthetic-resin frame so that they were parallel and 1 in. apart. They were immersed to a depth of 3·5 cm. in 250 ml. of solution contained in a 500-ml. beaker. The specimens were waxed at the water-line, also at the immersed cut edges, with a 5-mm. band of paraffin wax. The steel and aluminium specimens in each couple were connected through a 100-ohm resistance. The difference in potential was measured using a Cambridge pH meter with a megohm resistance placed in circuit to obviate any risk of polarization effects. All couples were immersed for one week, during which time measurements of the difference in potential were taken at suitable intervals.

Experimental Results

Duplicate, sometimes triplicate, experiments were carried out in all cases, and although the absolute values of potential difference agreed to within $\pm$ 10 mV., the general features of the e.m.f./time curves were quite reproducible. As absolute quantitative values are of secondary importance, and in any case difficult to obtain, owing to the heterogeneous nature of sprayed metal, this variation may be considered satisfactory.

Tests were carried out in : (i) Distilled and tap water ; (ii) sodium chloride solutions ; (iii) sulphuric acid solutions ; (iv) ammonium sulphate solutions ; and (v) aluminium sulphate solutions. These solutions covered the range of ions of most importance in the field of atmospheric exposure, and also enabled the effect of aluminium ions in solution to be examined.

The results for the variation in e.m.f. with time

are plotted in Figs. 1–5. In the majority of cases aluminium is cathodic to steel, and only in the more concentrated sulphuric acid and aluminium sulphate solutions is an anodic relationship obtained. In all solutions the tendency is for aluminium to assume an anodic value to steel as the corrosion process continues, although the rate at which this occurs varies considerably with the nature and concentration of the solution. In solutions in which steel is initially anodic, a maximum value for e.m.f. is obtained in the first few hours, after which there is a steady fall.

In distilled water, as would be expected, the total variation in e.m.f. is small. A maximum is reached after immersing for about 8 hr., and during the next 160 hr. the e.m.f. decreases by only 0·06 V. In tap water there is a somewhat greater rate of drop of e.m.f. amounting to 0·10 V. In sodium chloride solutions, as shown in Fig. 2, aluminium is always cathodic to steel over the concentration range and times of immersion tested. The initial e.m.f. increases with the concentration of solution, but the rate of drop of e.m.f. follows a similar proportionality. The maximum value of e.m.f., usually reached after immersing for about 8 hr., together with the total drop in e.m.f., are given in Table I. Even after one week's immersion no 'steady state' is reached, the e.m.f. still changing in the direction of an anodic value for aluminium.

Table I

E.M.F. IN SODIUM CHLORIDE SOLUTIONS

Concentration of Solution	Maximum e.m.f., volts	Total Drop in e.m.f., volts
M	0·475	0·24
M/5	0·34	0·18
M/10	0·22	0·12
M/1000	0·15	0·15

In sulphuric acid solutions of concentrations less than *M*/2000, steel maintains an anodic relationship (*see* Fig. 3), except in the case of *M*/3000 H_2SO_4, where there is a reversal of potential after immersion for 135 hr. There is a reversal of potential after immersion for 30 hr. in the *M*/2000 solution, aluminium becoming anodic, and there is a fairly rapid rise in e.m.f. after this. Table II gives the maximum values of e.m.f., together with the total change during the period of immersion.

In ammonium sulphate solutions having a concentration of *M*/200 to *M*/4000, steel is anodic over the whole period of immersion. The curves are similar to those obtained in sodium chloride solutions (*see* Fig. 4). In the most dilute solution tested (*M*/4000) a reversal of potential would occur just after one week's immersion. The essential data are given in Table III.

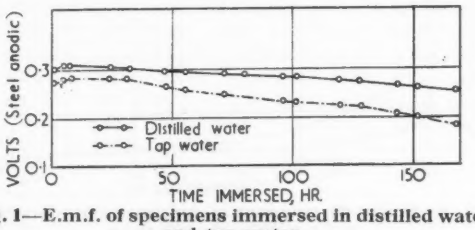

Fig. 1—E.m.f. of specimens immersed in distilled water and tap water

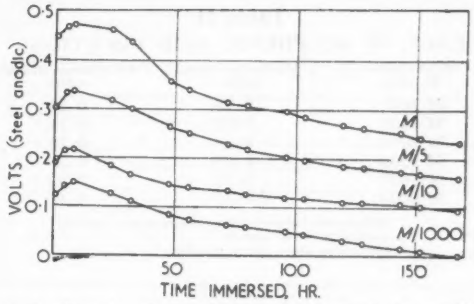

Fig. 2—E.m.f. of specimens immersed in sodium chloride solutions

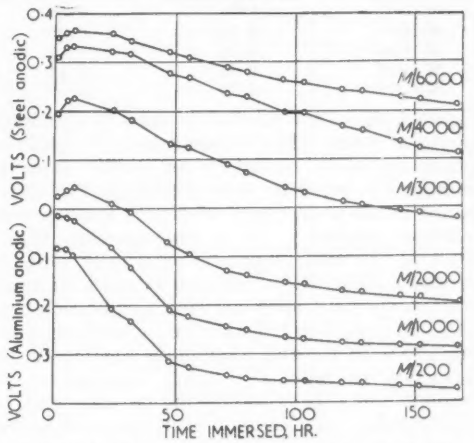

Fig. 3—E.m.f. of specimens immersed in sulphuric acid solutions

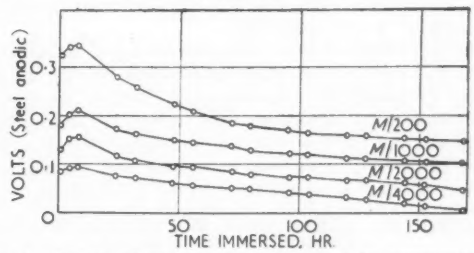

Fig. 4—E.m.f. of specimens immersed in ammonium sulphate solutions

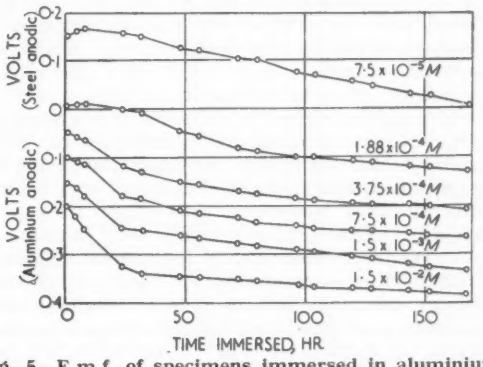

Fig. 5—E.m.f. of specimens immersed in aluminium sulphate solutions

Table II

E.M.F. IN SULPHURIC ACID SOLUTIONS

Concentration of Solution	Maximum e.m.f., volts	Total Change in e.m.f., volts
M/200	−0·08*	0·29
M/1000	−0·01*	0·28
M/2000	+0·05	0·25
M/3000	+0·23	0·25
M/4000	+0·33	0·22
M/6000	+0·37	0·16

* Minimum values where aluminium anodic
\+ Indicates steel anodic
− Indicates aluminium anodic

Table III

E.M.F. IN AMMONIUM SULPHATE SOLUTIONS

Concentration of Solution	Maximum e.m.f., volts	Total Drop in e.m.f., volts
M/200	0·35	0·20
M/1000	0·21	0·11
M/2000	0·16	0·11
M/4000	0·10	0·09

Figure 5 shows the results obtained in aluminium sulphate solutions. The concentration of aluminium sulphate necessary to ensure an anodic value for aluminium is very low, thus confirming the results obtained in the preliminary work with steel/sprayed-aluminium couples. At a concentration of $1{\cdot}9 \times 10^{-4}$ *M* the initial e.m.f. is practically zero, but after about 30 hr. the aluminium assumes an anodic character, the e.m.f. after one week's immersion being 0·13 V. In a solution twice as concentrated, the e.m.f. is initially 0·10 V., with aluminium anodic, and this corresponds to only a 0·025% solution of the crystalline salt. It is interesting to note that the anodic character of aluminium increases with increasing concentration of aluminium sulphate, whereas the opposite would be expected if only the effect of the aluminium ions on the electrode potential of aluminium were considered.

As this effect of small concentrations of aluminium ions was one of the most interesting results of the series of potential measurements, further work was undertaken to determine the effect of aluminium sulphate on : (*a*) the electrode potential of uncoupled steel immersed in various solutions, and (*b*) the corrosion of steel coupled to sprayed aluminium.

EFFECT OF ALUMINIUM SULPHATE ON THE CORROSION OF STEEL

Potential Measurements

Steel specimens, 5 cm. × 7 cm. × 20 gauge, polished with No. 0000 emery and degreased with carbon tetrachloride, were half immersed in 250 ml. of solution contained in a 500-ml. beaker. The waterline and cut edges of the specimens were waxed as in the previous series of potential measurements. The electrode potential of each specimen was observed at suitable intervals during one week's immersion by comparison with an *N*-calomel half-cell, each beaker being connected to its own calomel cell through a connecting bridge. Measurements were carried out in : (i) Distilled water ; (ii) *M*/100 sodium chloride ; (iii) *M*/2000 ammonium sulphate ; and (iv) *M*/2000 sulphuric acid, and in each of these solutions with the addition of aluminium sulphate to give concentrations of $3{\cdot}75 \times 10^{-4}$ *M*, $7{\cdot}5 \times 10^{-4}$ *M*, and $1{\cdot}5 \times 10^{-3}$ *M*.

The form of the curves obtained in each set of solutions was roughly similar, and only one curve, that for sodium chloride solutions, is reproduced (*see* Fig. 6). All solutions containing no aluminium ions exhibited the growth of a more negative potential for steel, and the solutions containing aluminium sulphate presented marked differences in the potential/time curves. It seems that there is a rapid establishment of a highly negative potential when steel is immersed in solutions containing aluminium sulphate. This is due to an increase in the cathodic area self-polarization caused by the deposition of aluminium hydroxide gel on the cathodic areas. A general feature of the tests was the absence of rusting on the steel immersed in the solutions containing aluminium ions. Even those solutions containing the least addition of aluminium sulphate showed only slight signs of rusting, and in the solutions containing a greater concentration the steel was usually completely free from rust. Associated with the absence of rusting was the early appearance of a white turbidity in solution, together with the slow deposition of a white deposit at the bottom of the beaker.

Measurement of the Rate of Corrosion

Two series of experiments were carried out : (i) To determine the effect of additions of aluminium sulphate to various solutions on the corrosion of uncoupled steel plates ; (ii) to determine the degree of corrosion of steel/aluminium-sprayed couples in various solutions.

In the first series of tests, mild-steel specimens, 5 cm. × 7 cm. × 20 gauge, were polished with No. 0000 emery and degreased with carbon tetrachloride, and fully immersed, at room temperature, in the solution contained in a 500-ml. beaker, so that the top edge of the specimen was 1 cm. below the liquid level. The specimen was suspended on a glass hook held in a rubber bung, containing two air holes, which fitted tightly into the mouth of the beaker. The time of immersion was 48 hr. in all cases. The loss in weight was obtained by scrubbing the specimens in running warm water. It was found that the corrosion product of specimens immersed in solutions containing no aluminium sulphate was easily removed, and there was no need for cathodic cleaning. The specimens immersed in solutions containing aluminium ions were covered with a film of considerable thickness, which was best removed by first scrubbing in distilled

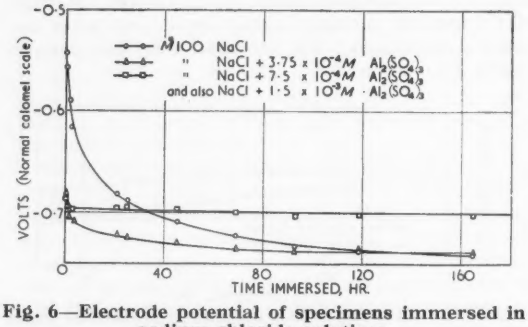

Fig. 6—Electrode potential of specimens immersed in sodium chloride solutions

Table IV

EFFECT OF ALUMINIUM SULPHATE ON THE CORROSION OF UNCOUPLED STEEL

Solution	Loss in Weight, mg./48 hr.					
	No Addition of Aluminium Sulphate		Concentration of Aluminium Sulphate			
			$3{\cdot}75\times10^{-4}$ *M*		$7{\cdot}5\times10^{-4}$ *M*	
		Mean		Mean		Mean
Distilled Water	10·0 11·2	10·6	18·9 17·1	18·0	26·1 26·9	26·5
M/100 Sodium Chloride	12·8 11·4	12·1	27·8 27·2	27·5	34·7 34·0	34·4
M/2000 Ammonium Sulphate	15·4 14·7	15·1	29·5 28·5	29·0	47·9 49·1	48·5
M/2000 Sulphuric Acid	17·6 17·1	17·4	37·9 36·9	37·4	58·3 57·5	57·9

water and then immersing in boiling distilled water, when the film became granular and powdery and was easily removed by brushing lightly with a very fine wire brush. The results for the loss in weight determination are given in Table IV.

The general feature of absence of rusting in the solutions containing aluminium sulphate was again observed, as in the preceding tests on potential measurements. Nevertheless there is considerable acceleration of corrosion, in which aluminium ions in solution must play an important part, as is shown by the white turbidity and deposit, which was found on analysis to be aluminium hydroxide. Practically the whole of the iron in solution was in the ferrous condition, so that dissolution must occur as ferrous salt, with subsequent slow oxidation to the ferric state. By careful handling it was possible to preserve almost intact the white film present on the specimens immersed in solutions containing aluminium sulphate. Upon drying, the film consisted of a powdery deposit which easily flaked off. The weight of the film was, in most cases, not less than the total loss in weight of the specimen, and for the specimens immersed in *M*/100 NaCl + $7{\cdot}5\times10^{-4}$ *M* $Al_2(SO_4)_3$, and *M*/2000 $(NH_4)_2SO_4$ + $7{\cdot}5\times10^{-4}$ *M* $Al_2(SO_4)_3$, the weights were 55 and 67 mg. respectively. There was a very small proportion of iron in this deposit, the bulk of it consisting of aluminium hydroxide. The mechanism of formation of the film is presumably dependent upon immediate reaction of the aluminium ions with hydroxyl ions liberated at cathodic areas. Only when the bulk of aluminium ions in solution has been precipitated as hydroxide, either to remain on the cathodic areas, or to be deposited away from the surface, will the iron begin to show rusting in the usual sense. The formation of the protective film over the cathodic areas is in agreement with the potential/time curves obtained for steel in solutions containing aluminium sulphate (*see* Fig. 6).

In the second series of corrosion tests, steel/sprayed-aluminium couples were set up in exactly the same way as in the tests involving measurement of e.m.f., except that the depth of immersion was 4·5 cm. The couples were immersed for 7 days, at the end of which time they were removed, and the loss in weight of the steel specimens was determined by washing off the corrosion products. Because of the porous nature of the sprayed aluminium it was impossible to determine relevant changes in weight of the aluminium specimens. The results obtained, together with losses in weight of control steel specimens, are given in Table V.

The results in Table V confirm those obtained in the preliminary series of tests with steel/aluminium-sprayed couples, and demonstrate the effect of aluminium sulphate additions in producing an anodic relationship for aluminium. Comparing the loss in weight of uncoupled steel after 7 days' immersion with that after 2 days', it is apparent that aluminium ions in solution lead to a stifling of the attack, so that the rate of corrosion decreases rather more rapidly than in solutions containing no aluminium sulphate additions.

The acceleration of corrosion, in the early stages of immersion, caused by aluminium sulphate additions, cannot be caused solely by the effect of the hydrolysis of this salt on the *p*H of the solution ; this is shown by Table VI, which gives the *p*H of solutions containing varying concentrations of aluminium sulphate. It is probable that the variation in *p*H, caused by additions of aluminium sulphate, is of minor importance, as aluminium ions in acid solution accelerate corrosion, yet the *p*H is increased slightly.

DISCUSSION OF RESULTS

There is little doubt that, over long periods of atmospheric exposure, aluminium offers sacrificial protection to steel. It is necessary, therefore, to link up this conclusion from field observation with the present experimental results and with the observed early rust-staining of aluminium coatings. A general feature of the e.m.f./time curves (Figs. 1–5) is the

Table V

EFFECT OF ALUMINIUM SULPHATE ON THE CORROSION OF STEEL/ALUMINIUM-SPRAYED COUPLES

Solution	Loss in Weight, mg./7 days			
	Coupled Steel		Uncoupled Steel	
		Mean		Mean
Distilled Water	27·9 23·6	25·8	19·5 17·6	18·6
ditto with $3{\cdot}75\times10^{-4}$ *M* $Al_2(SO_4)_3$	12·7 14·3	13·5	27·5 25·2	26·4
ditto with $7{\cdot}5\times10^{-4}$ *M* $Al_2(SO_4)_3$	4·6 3·6	4·1	35·9 32·1	34·0
M/100 Sodium Chloride	25·2 29·1	27·2	24·6 23·0	23·8
ditto with $3{\cdot}75\times10^{-4}$ *M* $Al_2(SO_4)_3$	13·9 15·7	14·8	43·6 37·9	40·8
ditto with $7{\cdot}5\times10^{-4}$ *M* $Al_2(SO_4)_3$	2·8 3·6	3·2	47·9 44·4	46·2
M/2000 Ammonium Sulphate	31·3 35·5	33·4	30·4 28·0	29·2
ditto with $3{\cdot}75\times10^{-4}$ *M* $Al_2(SO_4)_3$	13·6 15·1	14·4	47·0 43·2	45·1
ditto with $7{\cdot}5\times10^{-4}$ *M* $Al_2(SO_4)_3$	5·9 4·8	5·4	61·8 57·7	59·8
M/2000 Sulphuric Acid	6·5 5·4	6·0	33·6 32·6	33·1
ditto with $3{\cdot}75\times10^{-4}$ *M* $Al_2(SO_4)_3$	4·7 5·5	5·1	59·7 54·0	56·9
ditto with $7{\cdot}5\times10^{-4}$ *M* $Al_2(SO_4)_3$	2·6 3·8	3·2	74·1 67·8	71·0

tendency towards establishing aluminium as the anodic member of the couple. Even in those solutions in which steel is initially appreciably anodic, the e.m.f. decreases, and it is safe to assume that in most cases there will ultimately be a reversal of potential and consequent possible sacrificial protection by aluminium, provided that the current density is sufficient.[14, 15] Three factors are concerned in these changes of e.m.f.:

(i) Variation in the single-electrode potential of steel, mainly owing to the formation of corrosion products. This will normally cause an increase in the cathodic area self-polarization, leading to a more negative potential.

(ii) The effect of the formation of corrosion products on aluminium. Probably the most important factor in the variation in electrode potential of aluminium is the penetration and possible break-up of the oxide film by ions in solution.

(iii) Changes in *p*H and ionic concentration in the solution, owing to the corrosion process. Although in the series of tests involving e.m.f. measurements the ratio of area of specimen to volume of solution was rather high (35 sq. cm. to 250 ml.), it is probable that changes in the composition of the solution are negligible when compared to the ratio of surface to volume in atmospheric exposure.

The variation with time of the electrode potential of iron has been described in detail by Gatty and Spooner[16] and others. It is unnecessary to enter into a detailed discussion of this variation except to note that, in the absence of inhibitors, the potential of

Table VI

*p*H OF SOLUTIONS CONTAINING ALUMINIUM SULPHATE

Concentration of Aluminium Sulphate	*p*H			
	Distilled Water	*M*/100 Sodium Chloride	*M*/2000 Ammonium Sulphate	*M*/2000 Sulphuric Acid
None	5·72	5·90	6·10	2·97
$0{\cdot}3\times10^{-3}$ *M*	4·94	4·90	4·52	2·99
$0{\cdot}6\times10^{-3}$ *M*	4·86	4·78	4·41	3·07
$0{\cdot}9\times10^{-3}$ *M*	4·80	4·68	4·34	3·18
$1{\cdot}2\times10^{-3}$ *M*	4·75	4·63	4·28	3·31
$1{\cdot}8\times10^{-3}$ *M*	4·68	4·59	4·24	3·41
$2{\cdot}4\times10^{-3}$ *M*	4·64	4·54	4·17	3·47
$3{\cdot}0\times10^{-3}$ *M*	4·60	4·39	4·12	3·53

iron assumes a more negative value as the corrosion process proceeds. If, therefore, sprayed aluminium maintained a constant electrode-potential value the aluminium would be expected to become progressively more noble relative to steel. Furthermore, aluminium itself usually tends to give a more noble electrode potential. It has been shown that the reverse is the case when dealing with sprayed aluminium, and examination must be made, therefore, of the reactions which are occurring at the aluminium surface, resulting in changes in the electrode potential of the aluminium.

The presence of an oxide film on aluminium causes a more noble potential, and only by amalgamation, or by using special polishing techniques,[13] can the true value of the electrode potential be obtained. A sprayed aluminium deposit consists of an intimate, porous conglomerate, in which every particle of metal is encased in a layer of oxide. Moreover, in view of the method of producing sprayed coatings, in which molten particles are projected by an air blast on to the surface of the object to be coated, the oxide layer present around each particle must be severely strained by the rapid quenching effect, and considerably weakened by incipient cracking and flaking. With such a weakened γ-Al_2O_3 film many susceptible points would exist at which ions could penetrate to the basis aluminium. The conditions in the pores of a sprayed coating are, therefore, somewhat different from those on a polished sheet of pure aluminium. In the latter case the number of discontinuities is relatively few, whereas, in the case of sprayed aluminium, it is reasonable to expect a weak and easily penetrated oxide film, giving rise to many anodic areas at which corrosion of the underlying aluminium will occur. The particulate nature of a sprayed coating may also radically alter the initial stages and subsequent progress of corrosion, because of the importance of the orientation and distribution of oxide throughout the coating.

It is suggested, therefore, that there is a fairly rapid initial attack on the aluminium, causing the coating to become progressively less noble, until there is a reversal of potential and aluminium becomes anodic (where this is not initially established owing to the ionic equilibrium in the electrolyte). The influence of various ions on the penetration of the oxide film has not been fully worked out, but the slopes of the e.m.f./time curves give an indication of the relative effects of the solutions used in this investigation. The importance of oxygen in solution, as a cathodic depolarizer, is probably of considerable importance.

In the case of aluminium coatings on steel, several complicating factors arise, owing to the formation of corrosion products. If the coating thickness is less than 5 mil, it is permeable to liquids, and if the coating becomes 'flooded' in the early stages of exposure, rusting of the steel will usually occur, and continue until the polarity is reversed. The complicating factors disturbing the simple change in electrode potentials are :

(i) There will be deposition of corrosion products in the pores of the coating, thereby making it much less porous, and possibly impermeable[17]

(ii) Unless the sprayed coating is flooded with liquid, precipitation of the corrosion product from the the steel will take place below or within the coating, because of the accessibility of oxygen. Only when the source of oxygen is outside the coating will there be visible rust-staining[18]

(iii) The dissolution of aluminium, leading to the presence of aluminium ions in the corroding solution, will lead to results deducible from Fig. 5.

Topochemical factors, therefore, will be of decisive importance in affecting the initial protective value of aluminium coatings. In the initial period of atmospheric exposure, the corrosive influences of a polluted atmosphere, water vapour in the air, and daily condensation combine to produce three possible effects :

(i) Precipitation of corrosion products from the steel at the base of the coating

(ii) Clogging of the pores of the coating

(iii) Break-up of the oxide film around the aluminium particles.

With the combination of these three factors it has been found experimentally that a week's exposure to a normal industrial atmosphere is sufficient to ensure that no visible rusting through a 4-mil. coating will occur when flooding takes place. The unreproducibility of rust-stains in atmospheric-exposure tests is thus explained by the short time necessary for the change in coating structure and/or polarity to occur, and the fact that most long-period field tests have been carried out on specimens exposed vertically, in which position it is difficult to induce rust-staining, since the rain rapidly runs off. It follows that a good deal of the protective value of sprayed aluminium coatings may be caused by the corrosion products precipitated in the pores of the coating, as previously suggested by Ballard.[19] Evans has also made a similar suggestion that precipitated aluminium hydroxide plays a large part in enhancing the protective qualities of the coating.[12]

Any practical method of ensuring that no rust-staining will occur must saturate the coating with the particular ions that will give an anodic character to aluminium, even when introduced into adverse climatic conditions immediately after treatment. Alternatively, the pores in the coating must be effectively sealed. The former method offers considerable advantages in practice, and, on the basis of the results obtained above, a further investigation was made into the efficacy of various solutions in preventing rust-staining.

A standard procedure was worked out whereby reproducible rust-staining was obtained on untreated aluminium-coated steel. A 6-in. $\times$ 4-in. $\times$ 20-gauge mild-steel panel, to which had been applied a 3-mil. coating not more than 48 hr. previously, was sprayed with $M/100$ NaCl, using a hand atomizer, so that the surface was completely covered and flooded with liquid. The spraying with $M/100$ NaCl was repeated at half-hourly intervals for 4 hr., and after each spraying the specimen was placed in a large box, open at the top. Under these conditions of slow evaporation rust-stains appeared within 16 to 24 hr. Where the coating thickness was somewhat variable, rust-staining would occur even after 8 hr.

The following procedure was adopted when assessing solutions capable of suppressing rust-staining. The

solution under test was sprayed on to the specimen so that the aluminium coating was saturated to the limit of its absorptive capacity. Initial spraying with $M/100$ NaCl took place after 15 min., 1, 4, or 24 hr., and thereafter at half-hourly intervals for 4 hr. It was generally found that if rust-staining occurred it appeared, at most, within 24 hr. of first spraying with $M/100$ NaCl.

It was necessary to use a $1{\cdot}5 \times 10^{-3}$ M $Al_2(SO_4)_3$ solution to suppress rust-staining on the specimens sprayed with $M/100$ NaCl within 4 hr. of treatment. Less concentrated solutions allowed rust-staining to various degrees, and with the $3{\cdot}75 \times 10^{-4}$ solution it was necessary to allow an interval of 24 hr. between treatment and spraying with $M/100$ NaCl to obtain complete suppression. With all aluminium sulphate solutions there was a slight, unreproducible tendency to rust-staining, even without further spraying with $M/100$ NaCl. This tendency was found to be of greater importance when dealing with larger, commercial articles, although the overall beneficial effect of aluminium sulphate solutions was still not doubted. The tendency is presumably caused by local spots of bad electrical contact between the coating and the steel, so that corrosion of the steel occurs, rather than reversal of potential of the steel/aluminium-sprayed couple. These experiments on the corrosion of steel in aluminium sulphate solutions show that where such local spots exist in the coating, accelerated corrosion of the steel will occur, with the establishment of a more negative potential.

Sulphuric acid solutions, when used to treat aluminium-coated steel, gave rather better results than aluminium sulphate, and with $M/500$ H_2SO_4 it was possible to suppress rust-staining when the interval between treatment and spraying with $M/100$ NaCl was only 1 hr. On larger articles the $M/500$ H_2SO_4 gave much more encouraging results than any of the aluminium sulphate solutions tested.

The importance of the initial exposure conditions having been established for aluminium coatings on steel, it is obvious that, either these conditions must be controlled, or some treatment of the coatings must be given, such as the use of very dilute sulphuric acid or aluminium sulphate solutions. It has been shown that the use of very dilute sulphuric acid solutions is of great advantage in suppressing the formation of rust-stains, although not completely efficacious. It seems that changes in the structure of the coating, resulting in the filling up of pores, are equally as important in suppressing rust-staining, as reversal of potential, but which of these factors is likely to predominate when treating with dilute sulphuric acid solutions cannot be demonstrated at the present stage. A further study of corrosion processes in the aluminium coating itself will therefore be necessary before a full answer can be given to the problem of rust-staining.

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A special meeting of The Iron and Steel Institute is to be held on Tuesday, 18th October, 1949, to discuss papers on the corrosion and corrosion-fatigue of steel,

Details of the programme will be published in the News Section of the September issue of the *Journal*.

Open-Hearth Furnace Models

Part I—FLOW PATTERNS IN DUCTS

By J. H. Chesters, D.Sc.(Tech.), and A. R. Philip, M.A.

SYNOPSIS

An interpretation of the complex flow patterns observed in three-dimensional models of open-hearth furnaces demands a knowledge of the flow in much simpler systems. Studies have therefore been made of the flow patterns obtained in various two-dimensional geometrical shapes when water is introduced through jets and allowed to escape over weirs.

Certain conclusions have been reached concerning the entrainment that occurs and the inevitability of recirculation to replace the fluid removed by the jet from the surrounding medium in closed containers. The behaviour of the stream can be roughly described by stating that it appears to ' know where it is going.' For example, it starts to turn a corner before actually reaching it.

Certain arrangements, for example, that of a jet introduced along the major axis of an ellipse, are inherently unstable, while others, such as the aiming of a jet symmetrically into one corner of an equilateral triangle, are peculiarly stable. Many of the patterns are maintained over wide ranges of flow rate, though the amount of dead space tends to decrease with increasing jet velocity.

Opposing jets frequently set up very complex patterns, and it is not unusual for the fluid entering in one jet to leave the system only after subsequent entrainment in another jet. In such cases it frequently travels a distance many times that between the entry and exit points. Jets impinging on one another at right-angles behave in a peculiarly critical manner which explains the necessity of maintaining a reasonable gas/air ratio in furnaces employing this method of mixing.

FURTHER consideration of the work described in the report on "*The Influence of Port Design on Open-Hearth Furnace Flames*,"[1] (*loc. cit.*, pp. 161 and 164) showed two immediate needs :

(1) The extension of instrumentation and, if possible, of automatic control on open-hearth furnaces with a view to maintaining optimum combustion conditions.

(2) More information regarding flow patterns in furnaces, and in particular the effect of detailed changes in port design on mixing rates and velocity distributions within the furnace chamber.

Great progress has been made during the last few years with the question of instrumentation, and a number of automatic control systems are now being tried out in various steelworks.

The present series of papers attempts to provide an elementary answer to the second question of flow patterns in furnaces. Preliminary work, using water in transparent three-dimensional scale models, showed that the answer would be a complex one, and that interpretation of the patterns obtained required a considerable amount of background knowledge. It was the lack of such knowledge that led to the elementary work on geometrical models reported in the present paper.

LITERATURE ON FLUID FLOW

Most of the data available on flow patterns refer to aerofoils and ships. This is not surprising since such information was demanded by the rapid development of air and sea transport, but it is remarkable that even the most elementary information regarding flow inside containers, *e.g.*, circular, square, and triangular dishes, does not seem to be available in the literature.

A great deal of work has of course been done that is relevant to the problem, *e.g.*, the classical studies on fluid mechanics, hydromechanics, and aerodynamic theory, but very little of this is applicable to furnaces without the assistance of new experimental data. The technical background cannot, of course, be reproduced in the present paper, but some reference should be made to it for those who wish to pursue the matter in more detail.

Fluid Mechanics

The subject of fluid mechanics deals mainly with the study of flow through pipes or over weirs, and with the design of such things as orifices, venturi throats, pumps, and propeller blades. Most of the early attempts to study fluid flow were empirical, and the complexity of the problem has led to many empirical equations which persist because of the lack of any adequate theoretical treatment. Numerous textbooks are available on this subject, *e.g.* "*Fluid Mechanics*," by Dodge and Thompson,[2] and "*Hydraulics*," by Lea.[3]

Classical Hydromechanics

The elaborate mathematical theory which is involved in classical hydromechanics is, for the most part, applicable only to non-viscous fluids. One of the standard works on this subject is Lamb's "*Hydrodynamics*."[4] An excellent treatment of the

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Dr. Chesters and Mr. Philip are at the Research and Development Department of The United Steel Companies, Ltd., Swinden House, Moorgate, Rotherham.

basic principles is given in Part I of "*Fluid Mechanics for Hydraulic Engineers*," by Rouse.[5] Certain types of problem are susceptible to direct treatment by inviscid flow theory, but many technical problems cannot be handled in this way because the viscosity of the fluid is an essential part of the problem.

Aerodynamic Theory

A very extensive literature, dealing in particular with heavier-than-air flight and ships' hulls, exists on the subject of aerodynamic theory. It includes boundary layer theory and aerofoil theory. The former was originally developed by Prandtl[6] in 1904, but has since been developed by many other workers, *e.g.*, Taylor and Fage. Typical textbooks are "*Aerodynamics*" by Piercey[7] and "*Applied Aerodynamics*," by Bairstow.[8] A good account of the general theory is given in "*Modern Developments in Fluid Dynamics*," edited by S. Goldstein.[9] Boundary layer theory is mainly concerned with the flow conditions resulting from the passage of various-shaped bodies through a surrounding real fluid.

Study of Velocity Distribution

The angle of spread in jets has been studied by Prandtl,[10] who developed an expression for the shearing stress between adjacent layers in a jet. Tollmien[11] subsequently used this expression to study the mixing of a current of air, moving at uniform speed, with the initially static air around it. He obtained in this way an expression for the velocity profile of a jet issuing from a point source into still air. Tollmien's work was extended by Kuethe,[12] who developed equations for a jet issuing into a parallel fluid stream moving at a slower velocity, and for a circular jet of finite cross-section at entry.

The work of Rummel[13] has shown that the speed of combustion of diffusion flames, such as occur in large furnaces, is mainly governed by the rate of mixing of air and gas. Rummel made use of an experimental burner and combustion chamber to study the rate of mixing in flames produced when air and gas issued from two flat rectangular nozzles placed side by side. These could be set to give various angles of impingement, a blank tongue of variable thickness being fitted between the nozzles. He found that :

(*a*) The combustion-chamber volume required to burn the gases is much less when there is a big difference of velocity between the air and gas, or when the air and gas velocities are simultaneously increased.

(*b*) The buoyancy due to temperature difference does not help appreciably in mixing, but the use of a gas having a lower N.T.P. density, *e.g.*, one high in hydrogen, accelerates mixing.

(*c*) A thick tongue of brick between the air and gas streams greatly increases flame length, while a large angle of impingement between the two streams greatly reduces it. The mixing space required with jets at 90° to one another was only one-sixth as large as when the jets were parallel.

(*d*) Combustion at the end of the flame is greatly accelerated if the flame strikes a wall or passes round a narrow bend.

(*e*) Excess air accelerates the whole combustion process and not merely combustion at the end of the flame.

Davis[14] has since developed the foregoing theory, applying it for example to boiler firing, while Allan[15] has suggested certain modifications to the formulae developed by Tollmien and Kuethe. In most of the above work, attention has been focused on the fast-moving fluid forming a jet, rather than on the surrounding fluid into which the jet issues. It is normally assumed that the surrounding media can be considered as at rest or moving parallel with the jet, in spite of the entrainment which must occur in the mixing zone. A study of the fluid system as a whole still remains to be carried out.

Considerable work has of course been done on combustion in jets, *e.g.*, by Townend, and more recently by Garside[16] and his co-workers.

Reference should also be made to the great amount of work done on tidal models, in which use has been made of similarity principles to study erosion at river bends, silting-up, and other allied problems, together with tests of such remedies as breakwaters. A good summary of this work is given in a recent book by Allen,[17] entitled "*Scale Models in Hydraulic Engineering*."

MODEL WORK

Comparatively little work has been done with actual furnace models, but the technique of model work in general and its dependence on the laws of similarity has received considerable attention, particularly during the last twenty years. A full review of the work done up to 1939 was given by Johansen[18] in his paper on "*Research in Mechanical Engineering by Small Scale Apparatus*." This is a long article (over 100 pages) covering a wide range of models, some of which have no aerodynamic interest. The paper gives, however, a most encouraging background, since it shows that models have been the means of major development in many fields besides ships and aeroplanes.

Air

No one who has smoked a cigarette can say that he has no knowledge of jets, but the study of the complex pattern obtained even with a puff of smoke calls for an advanced experimental technique, for example, high-speed photography.

One of the earliest and most useful techniques is that described as the Schlieren (striae) method. This was originally developed in 1867 by Töpler,[19] who made use of the change in refractive index due to change in density of air, employing an optical improvement of an already well-known phenomenon. Everyone is familiar with the pattern cast on a wall by light shining through a flame, or over a hot surface. The striae set up are clearly visible, but can be made far more pronounced by the use of a critical optical system such as that employed by Töpler, whose procedure has been widely used in the study of the disturbances produced by the passage of projectiles or aerofoils through fluids.

Use has also been made of air models in the recent development of jet engines, as described, for example,

by Watson and Clarke,[20] whose work possesses the great advantage that studies were made initially with cold air and later with actual engines working under normal operating conditions. The studies made by these and other workers on the flow pattern in flame tubes have done much to accelerate the remarkable development of the jet engine in this country.

Norton[21] suggested as far back as 1924 the use of scale models, both hot and cold, for the study of kiln and furnace design. Unfortunately, most of his paper is given up to a discussion of similarity and to the design of the models rather than to the results obtained with them.

The work at present being carried out on air models of open-hearth furnaces by the British Iron and Steel Research Association has been described in a preliminary paper by Newby.[22] This deals with the pressure losses in ports, but further work on mixing, using a similar model, has given most interesting results.[23]

Hansen and Jaroschek[24] stressed the ease with which models can be changed without any loss of production. They state that model work on boilers led to a reduction in the draught required of from 50 to 80%, in spite of the fact that only certain design features could be altered. They also claim great improvements from the study of models of cooling towers. Stanek[25] has made similar studies with two-dimensional models of reheating furnaces, using dyes in water or smoke to give visualization. His paper includes sketches of the flow patterns set up and indicates the possibility of improved distribution by changes in design. The work of Saunders[26] and his co-workers, on blast-furnace models, and of Hughes[27] on gas-producer models, is also indirectly relevant to the problem in hand.

Water

Endless examples could be given from everyday life of flow patterns in liquids, *e.g.*, the mixing of hot and cold water in a bath, made visual by the pattern thrown on the bath itself due to the varying refraction of light rays from a lamp. When a spoon is dipped into soup the latter will be seen to flow across a diameter to the opposite side, divide, and return along the circumference to the entry point. On reaching this point it is entrained by the incoming soup and circulates until the spoon is full.

The extensive work carried out on tidal models, as reported, for example, by Allen,[17] has already been discussed. The more relevant work that will occur to most readers is that of Groume-Grjimailo,[28] on the flow of gases in furnaces. This work has been discussed in some detail by Etherington[29] in his book of "*Modern Furnace Technology*." It is sometimes assumed that Groume-Grjimailo's work deals mainly with flow patterns, but in fact it is principally concerned with the study of buoyancy. Groume-Grjimailo pointed out that many of the apparently peculiar characteristics of furnaces could be explained by assuming that hot gases in a relatively cool chamber would tend to rise and that their behaviour could be simulated by using a furnace model upside down and injecting water ; or alternatively by using the model the right way up and simulating the hot gases in the cooler air by means of kerosene (sp. gr. 0·80) injected into water. Buoyancy studies made in this way provided useful data on the correct position of entry and exit points or baffle walls. The results of this work bear little relation, however, to the present flow-pattern studies, since buoyancy is likely to be a major factor only in the central portion of an open-hearth furnace. At the incoming end, the jet speeds are high and the density differences are small, while at the exit end, mixing should be fairly complete and no serious density difference should remain, provided of course, that no serious air infiltration occurs.

A much more relevant research is that of Rosin,[30] on "*Aerodyanamics as a Basis of Modern Fuel Practice*." This paper contains a clear and simple statement of the usefulness of models in studying combustion problems, and it possesses the added advantage that many of the models have been checked in practice and the results obtained have been found to agree with the predictions made. Rosin makes one point of which the present authors themselves have become very aware, *viz.*, that models are a great stimulus to thought and may lead to designs that would otherwise never have emerged. Some of Rosin's early work was done with cylinders, cubes, or rough lumps of rock salt, which were allowed to dissolve in flowing water. The shapes assumed by these lumps reveal quite clearly the eddies set up by the impact of the water stream on them. The rapid wear of salt in the region of an eddy may well be compared with corrosion of refractory materials, *e.g.*, in a furnace door, due to eddying gases rich in iron oxide, though it may not simulate erosion due to purely physical factors. Reference will be made in Part III of this series of papers to the extraordinary eddy formation observed in the uptakes of certain open-hearth furnace models. Rosin shows pictures (*see* Fig. 5*a* of reference 30) of an eddy set up when a gas jet leaves a single burner, or a multiple burner with thin or thick partitions between jets. Use has been made of such models to develop special high-turbulence burners suitable for the combustion of powdered fuels in locomotive fireboxes. Other examples given by Rosin are the design of vertical-chamber coke-oven walls and pneumatic-circulation driers for coal or agricultural uses. The coke-oven models were used to study the mixing of gas and air, the filling of flues with flame, and the distribution of gases across the heating ducts.

Clements,[31] in an earlier paper, described a model used to demonstrate flow in an open-hearth furnace. This model was two-dimensional and included furnace chamber, slag pocket, and checker chamber. It is interesting to note that even a simple model revealed remarkable eddy formation in the checker chamber and slag pocket and an area of relatively dead space between the flame and the furnace roof. It will be shown in Part III, not only that such dead spaces exist, but that in virtually all furnaces a considerable return flow against the general flame direction can be expected. Many other references could be quoted, *e.g.*, Leaf,[32] in his work on locomotive fireboxes, showed that improved results could be expected from

the introduction of special baffles, a prediction confirmed by subsequent full-scale trials.

Marcard,[33] in his paper on questions on flow relating to boiler and firing installations, gives numerous examples of the use of models. The first application refers to the design of control valves, but his main work appears to have been connected with boilers, where flow studies are required in four different media, *viz.*, water, steam, air, and combustion gases. He divides the problem into two main subheadings: (*a*) The reduction of undesirable resistances in the system, and (*b*) the production of sufficient turbulence to ensure good mixing. Marcard finds (as have the present authors with open-hearth furnaces) that almost all the flow speeds concerned are high enough to come in the turbulent region. He stresses the difficulties associated with correction for temperature and non-homogeneity, but points out that in spite of these difficulties useful information can be obtained. The most interesting aspect of his work, from the standpoint of the present research, is that which deals with combustion gases. Marcard has shown, for example, how a certain distribution of the water tubes in a boiler can lead to more uniform velocities. He also studied the methods of introducing air below a chain grate stoker, and found that only about 60% of the volume below the grate was normally in use because of the setting up of eddies and associated dead space. Perhaps his most interesting demonstration is the use of secondary air to promote localized turbulence and, therefore, more rapid combustion.

Knorre[34] made use of water models in the development of combustion chambers for burning peat, while Fossett and Prosser,[35] in a very recent paper, describe the application of models designed to show the best use of free jets for the mixing of fluids in bulk.

Finally, reference should be made to the unpublished work of the Rockware Glass Syndicate Ltd., who used water models for the study of glass-tank checker fillings. It was partly as a result of information supplied by this company that the authors' open-hearth furnace model was constructed.

Hot Models

Most readers will be familiar with the work of Leckie[36] and his co-workers, on the model furnace operated by the British Iron and Steel Research Association at the works of the Shelton Iron, Steel and Coal Co., Ltd. The results obtained by these research workers are more directly applicable to open-hearth furnaces than is any other model work at present in hand. It enables furnace characteristics to be worked out and the relative efficiencies of various types of port design and their probable effect on roof-temperature distribution to be determined. It is not easy, however, to study flow patterns in such models, for although pitôt tubes could be inserted, their manipulation would be difficult and their presence might interfere with the accuracy of the heat-transfer experiments which are at present the principal objective.

Reference has also been made to the work of Watson and Clarke,[20] which, together with similar work done by the National Gas Turbine Research Department and other investigations, has greatly added to the existing knowledge of flow in combustion engines. The work of Schultz-Grunow[37] is also of considerable interest, since he was able to photograph actual flames inside a model boiler. Although the full-scale boiler was to be fired with pulverized fuel, it would appear that Grunow used propane gas in his model. Grunow demonstrated that, although it was impossible to apply all the similarity conditions simultaneously in one model, a reasonable measure of similarity could be achieved and that corrections could be made for dissimilar conditions. Grunow's first model was built with double glass walls, but he subsequently changed these to mica windows, presumably to obviate cracking.

Certain of the recent work of Garside[16] and his co-workers, on the combustion of jets, is also of interest in connection with hot model work, since their photographic technique enabled very beautiful pictures to be taken of the eddies set up at the interface between the jet and the surrounding air.

ELEMENTARY GEOMETRICAL MODELS

It is with some hesitation that the authors enter a field of research in which they are admittedly amateurs, but the apparent lack of data on some of the more simple aspects of flow has forced them to do so. It seemed certain that such relatively simple processes as the flow of water in circular, elliptical, or square trays, would have been studied and recorded in the literature, but in spite of an extensive search and much expert advice, they have been unable to find any such set of standard patterns. The work described below arose directly out of difficulties experienced in interpreting the patterns obtained in three-dimensional scale models of open-hearth furnaces. Even a few tray experiments carried out initially under quite primitive conditions sufficed to show that certain of the indications from open-hearth models were not only conceivable, but might have been expected with any design in which a high-speed jet entered a vessel containing a fluid at rest or moving at a relatively low speed. The outstanding feature in all the open-hearth model work had been the *recirculation* of part of the furnace gases and also of a considerable part of the air supplied to the furnace. Since such recirculation has been observed in every one of the simple systems studied, it would indeed be surprising if it had been absent with such a complex shape as the open-hearth furnace. It is not claimed that the patterns described below have any absolute significance, nor that they are all completely reproducible, but without some such background it is extremely difficult to interpret the more complex flows encountered even in a cold model.

The Experimental Arrangement

A number of perspex dishes, approximately $\frac{7}{8}$ in. deep and of different geometrical shapes, each of which could be considered as inscribed in a 12-in. dia. circle, were prepared. The dishes were placed on a baseplate of opalescent perspex, which was illuminated from below by means of photoflood lamps

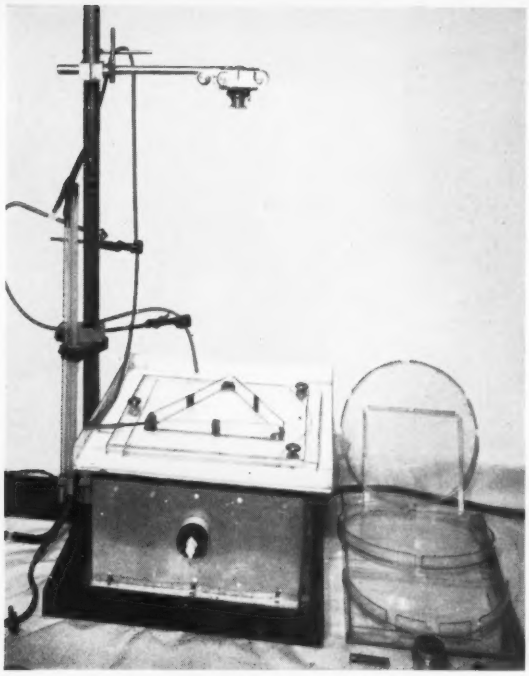


Fig. 1 – Apparatus for photographing flow patterns

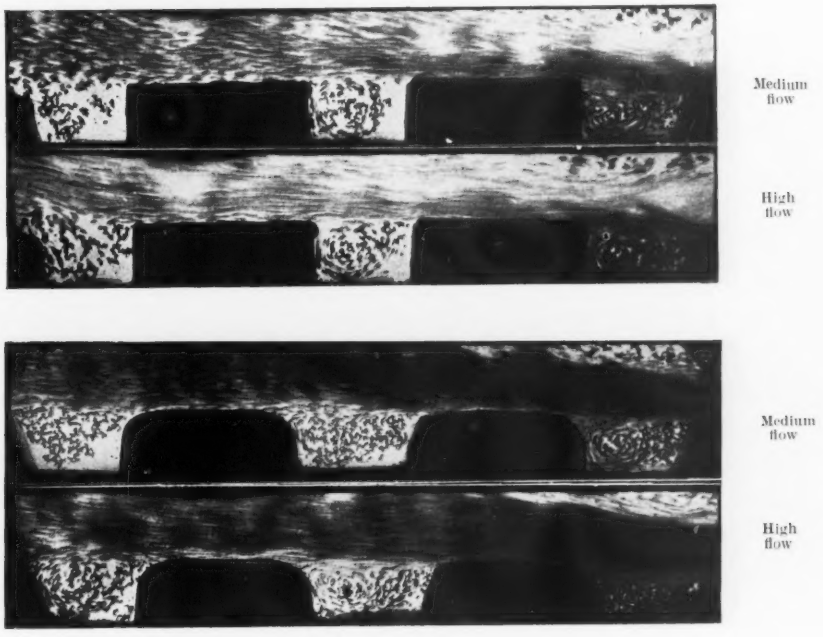
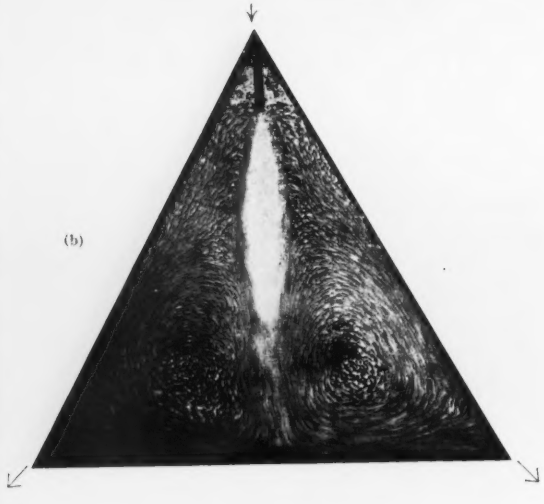


Fig. 2—Two-dimensional studies of flow past furnace doors ; (a) and (b) square pillars ; (c) and (d) rounded pillars

(a)

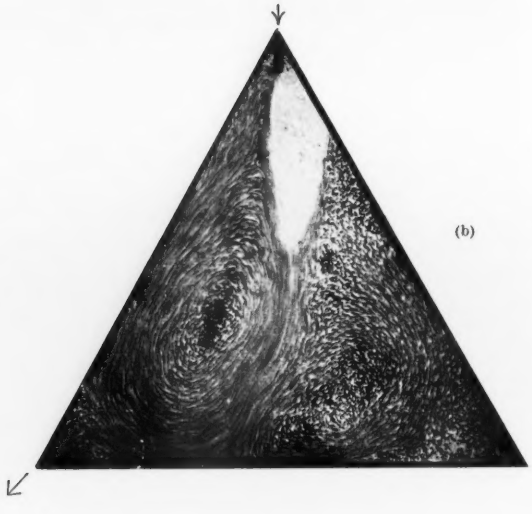
Low flow

(a)

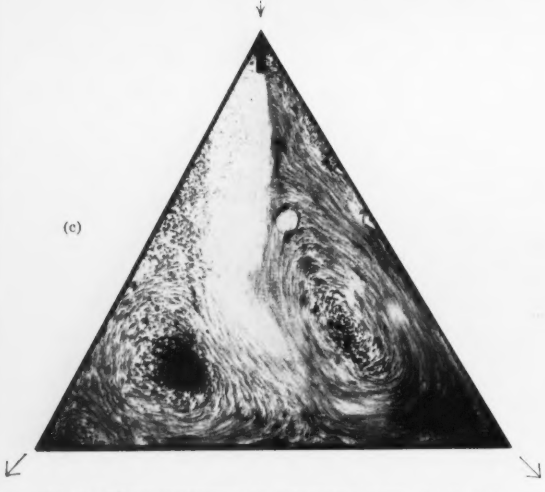


(b)

Medium flow

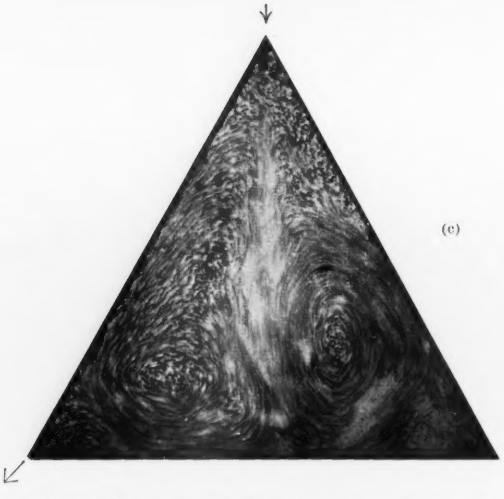


(b)



(c)

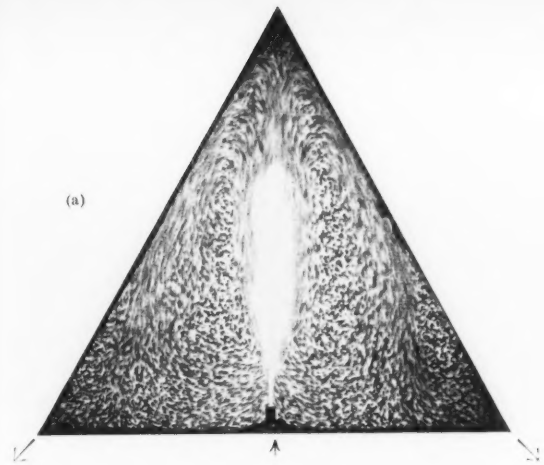
High flow

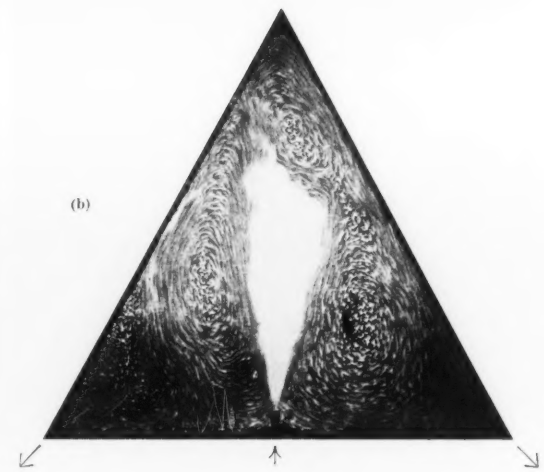


(c)

Fig. 3—Flow patterns in triangles with single jet entering one corner along bisectrix, and double exits

Fig. 4—Flow patterns in triangles with single jet entering one corner along bisectrix, and single exits





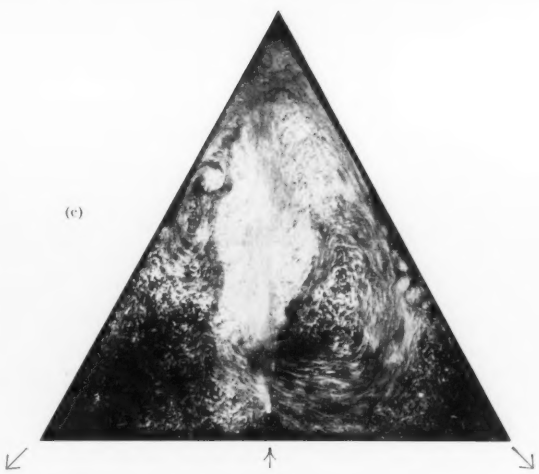


Fig. 5—Flow patterns in triangles with single jet directed through centre of a side towards opposite corner, and double exits

Low flow

Medium flow

High flow

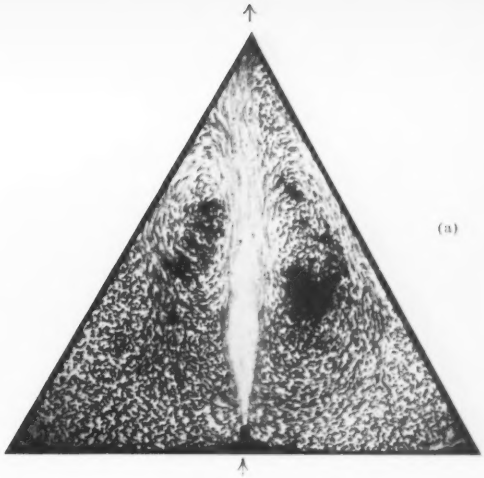
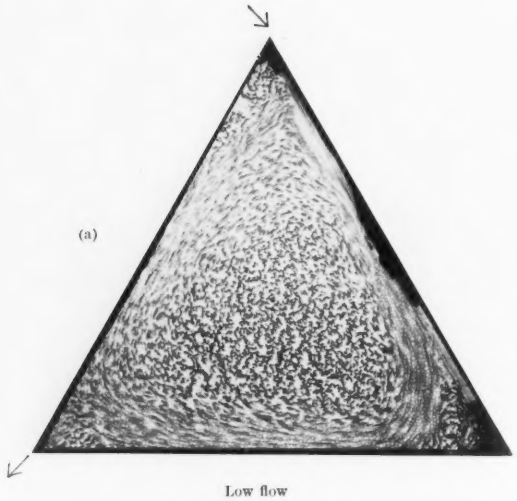
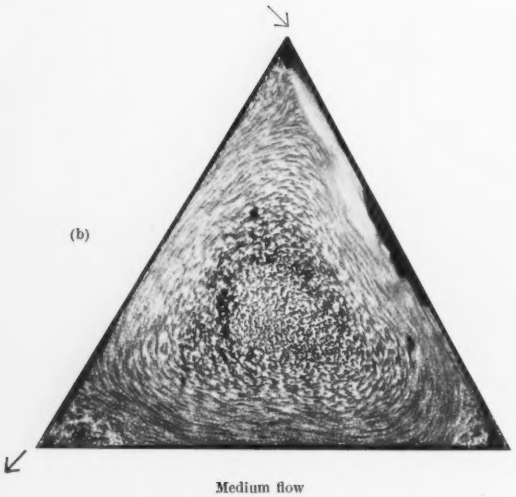


Fig. 6—Flow patterns in triangles with single jet directed through centre of a side towards opposite corner, and single exit



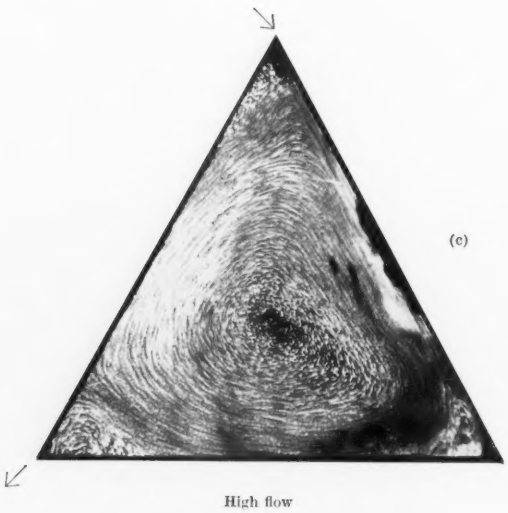
(a)

Low flow



(b)

Medium flow



(c)

High flow

Fig. 7—Flow patterns in triangles with single jet entering parallel to one side

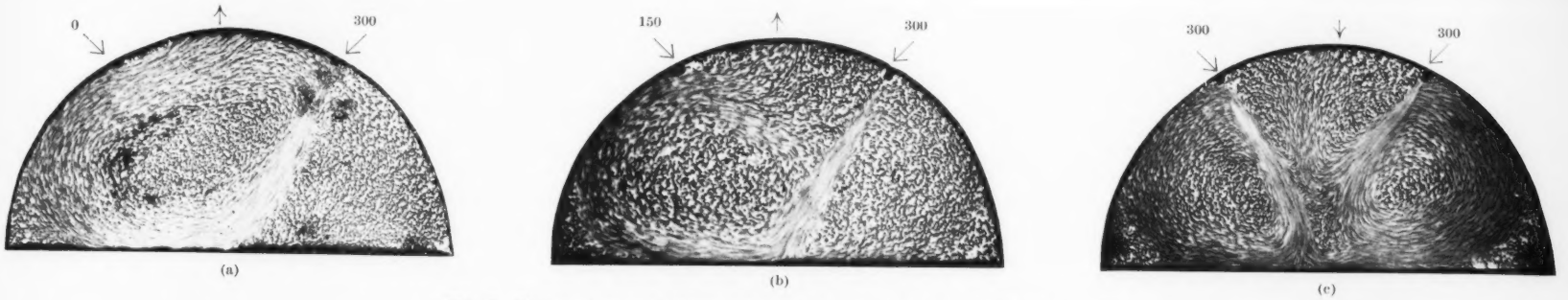
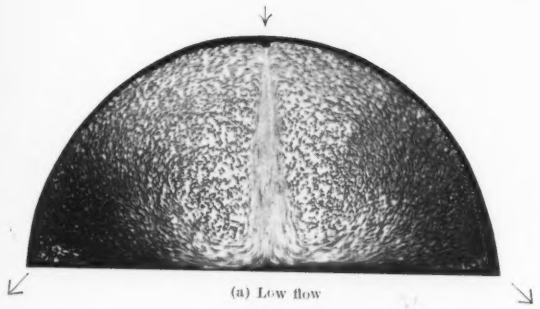


Fig. 8—Effect of varying flows (shown in c.c./min.) in a twin-jet system



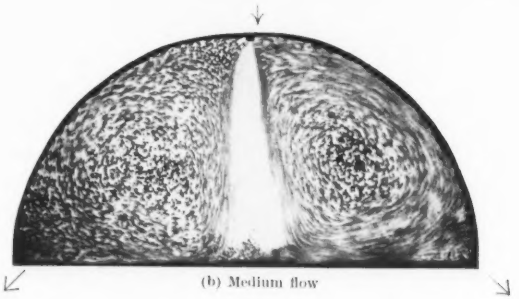


Fig. 9—Jet directed from centre of arc to centre of circle

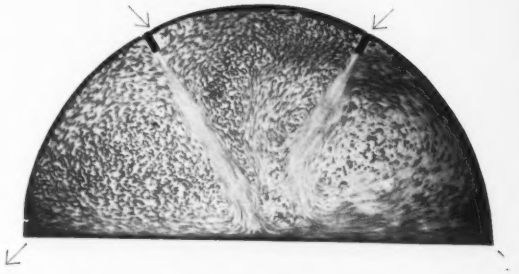
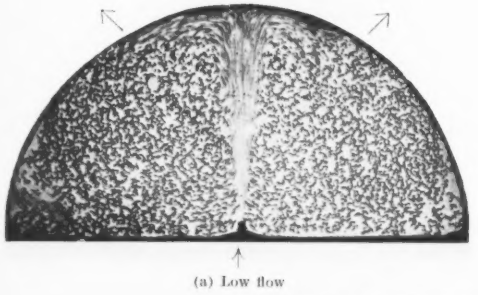


Fig. 11—Twin jets directed to centre of circle



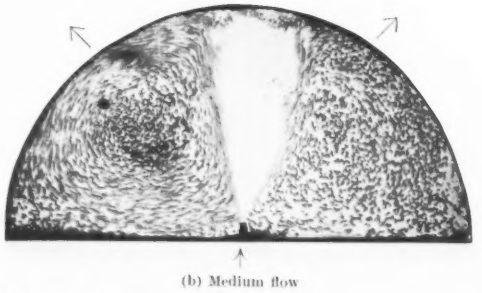


Fig. 10—Jet directed from centre of circle to centre of arc

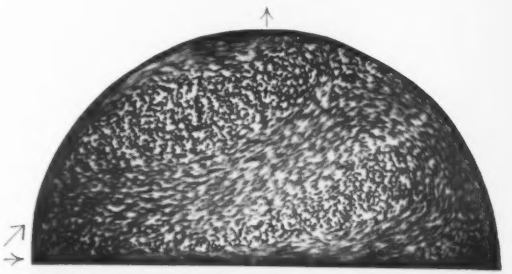


Fig. 12—Twin jets directed along sides from one corner

Figs. 8 to 12—Flow patterns in semi-circles

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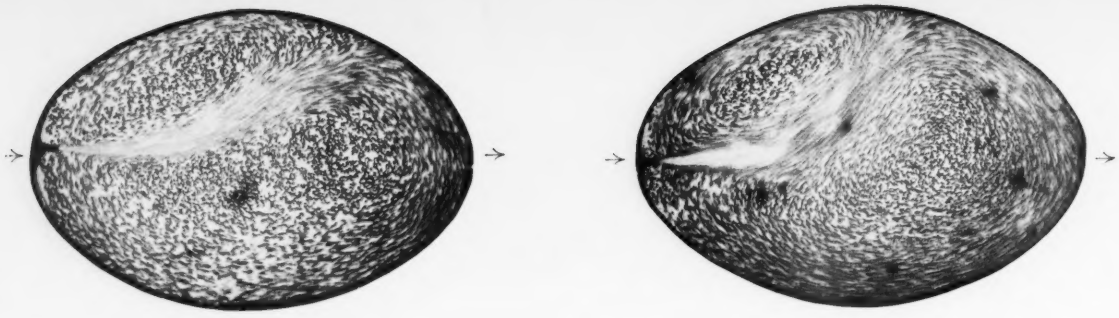
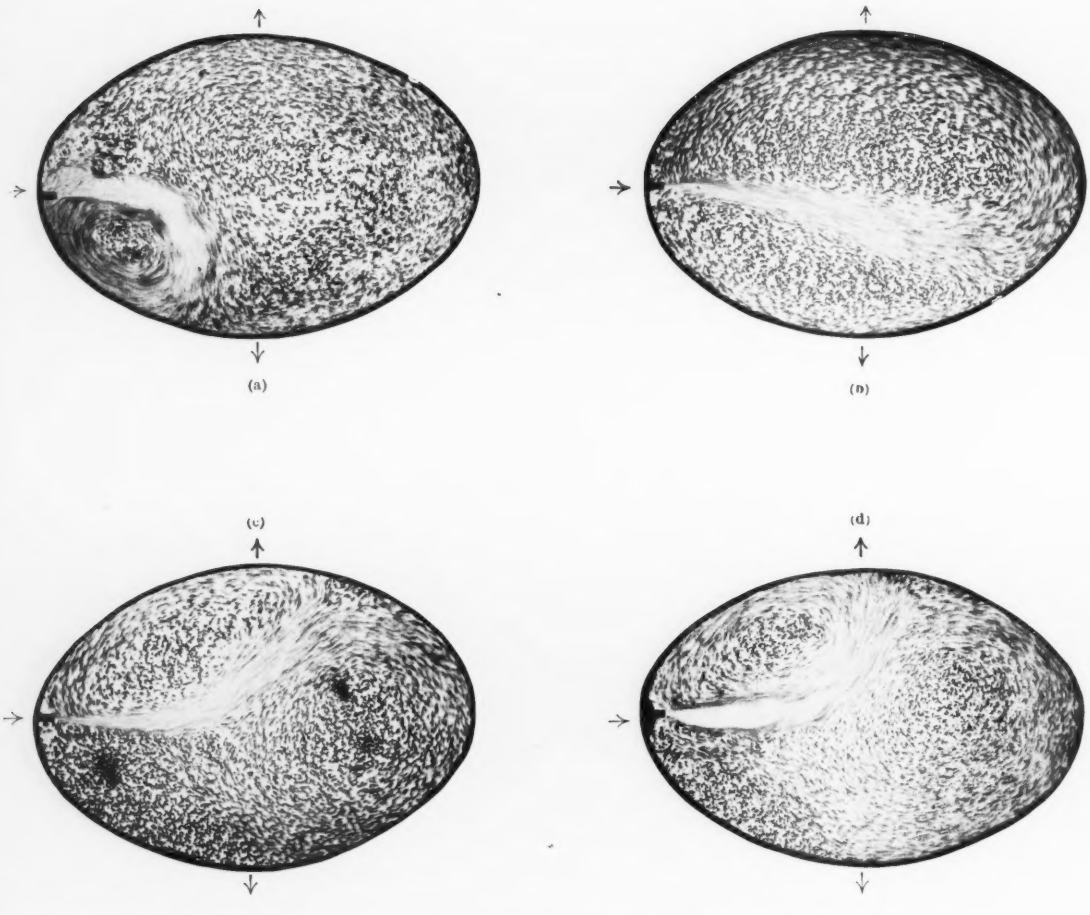


(a) Low flow (b) Medium flow

Fig. 13—Jet entering along major axis, with single exit



(a) (b) (c) (d)

Fig. 14—Four positions of unstable ' swinging ' jet. Single entry with double exits

Figs. 13 and 14—Flow patterns in ellipses

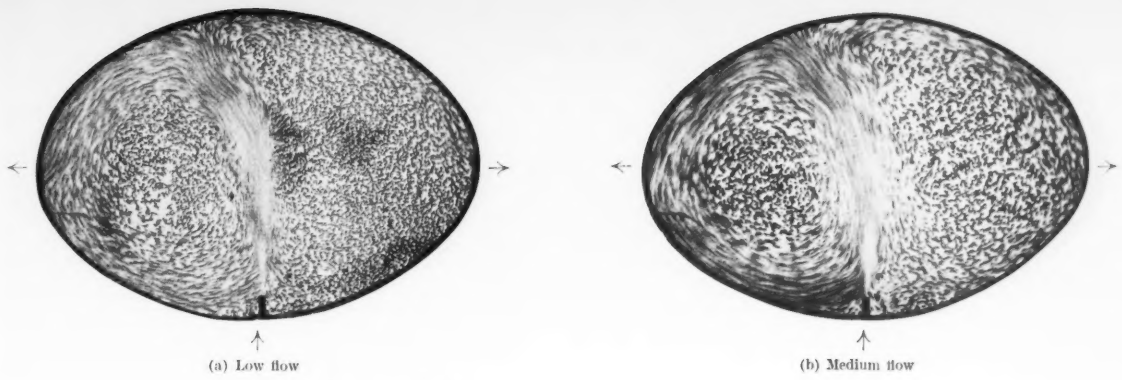


Fig. 15—Jet entering along minor axis, with double exits

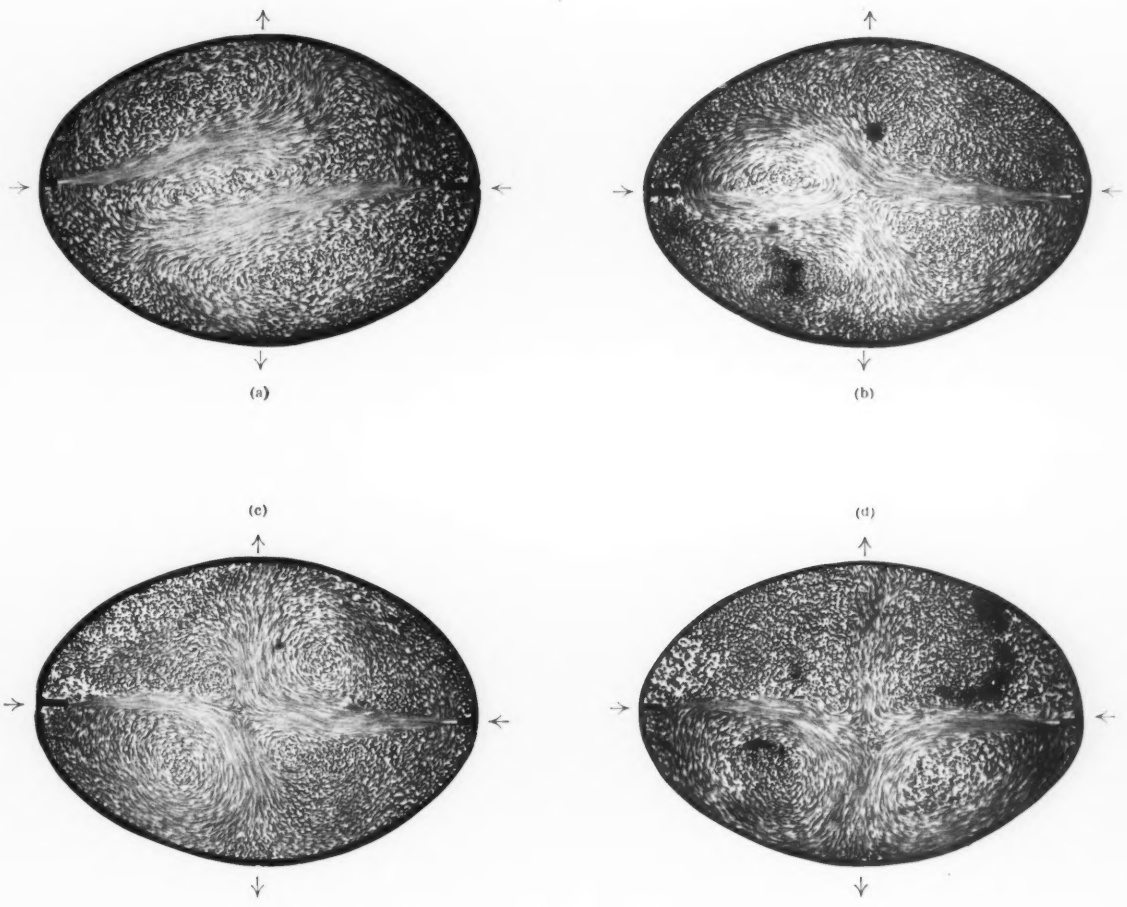


Fig. 16—Unstable patterns of opposing jets, with double exits

Figs. 15 and 16—Flow patterns in ellipses

Fig. 17—Jet across diameter, with single exit

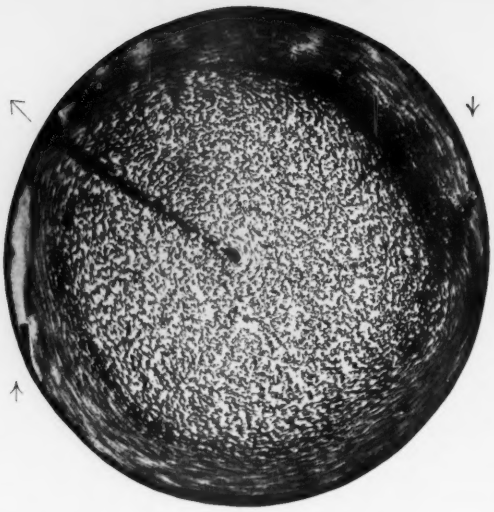


Fig. 18—Tangential jets, with central exit

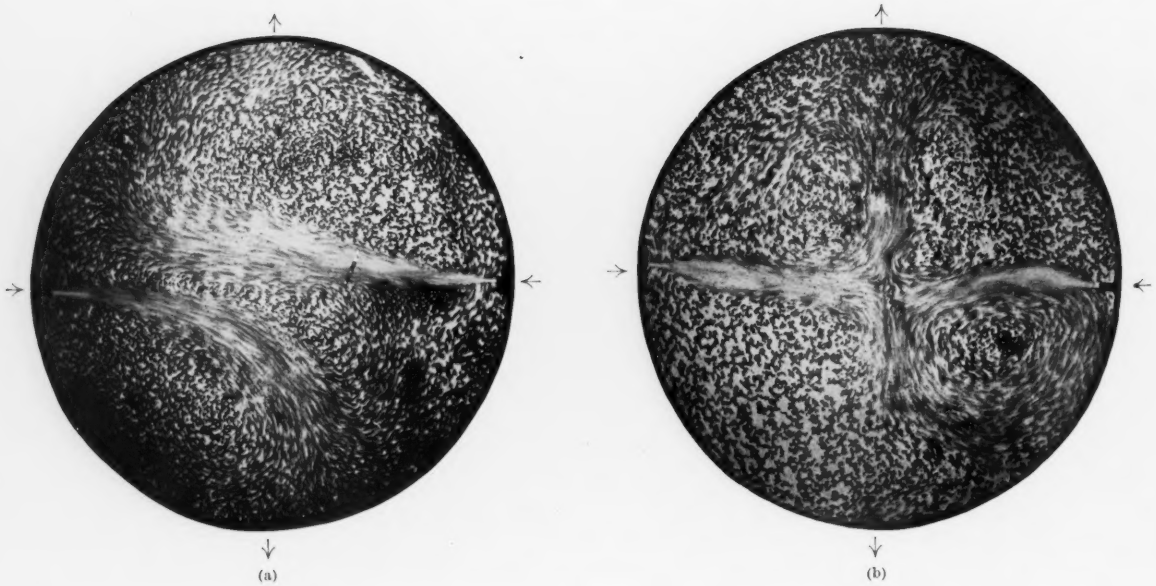
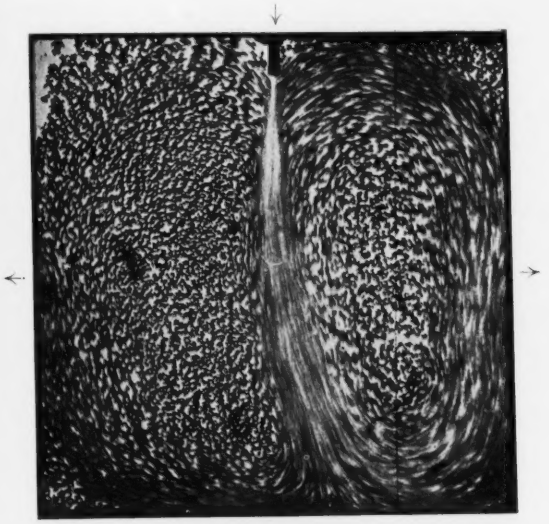
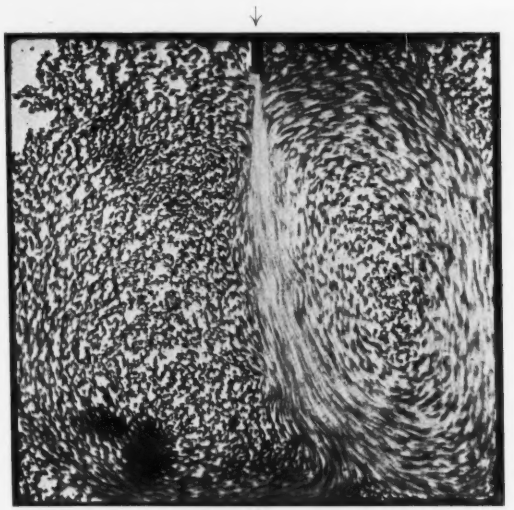


Fig. 19—Unstable patterns of opposing jets, with double exits

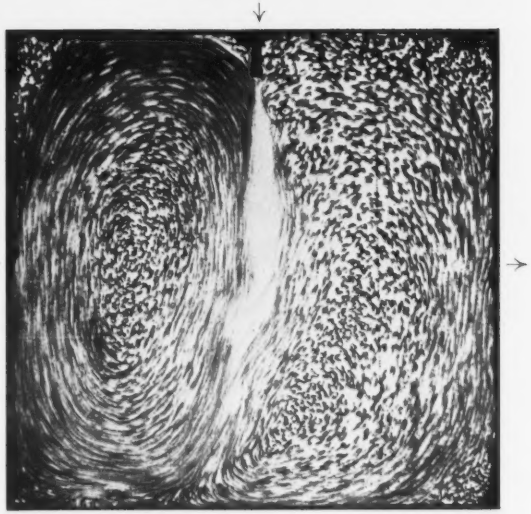
Figs. 17 to 19—Flow patterns in circles



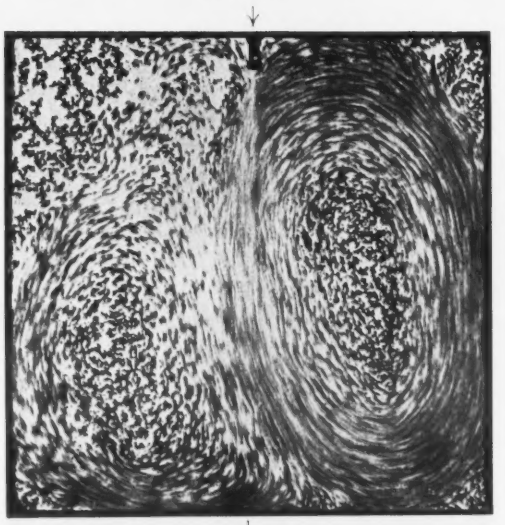
(a) Low flow



(b) Low flow

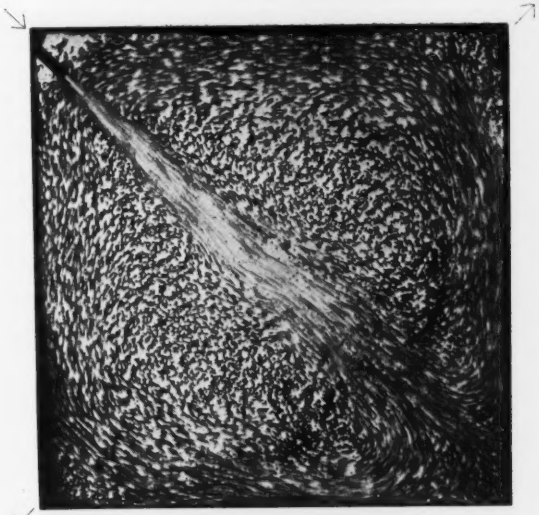


(c) Medium flow

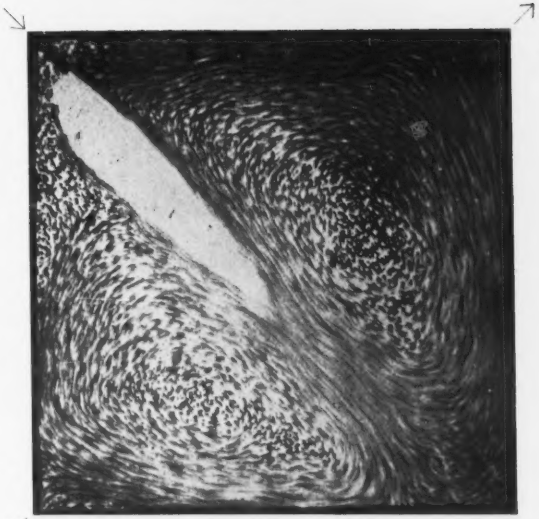


(d) Medium flow

Fig. 20—Jet directed through centre of side towards centre of opposite side, with single and double exits



(a) Low flow



(b) Medium flow

Fig. 21—Jet entering along diagonal, with double exits

Figs. 20 and 21—Flow patterns in squares

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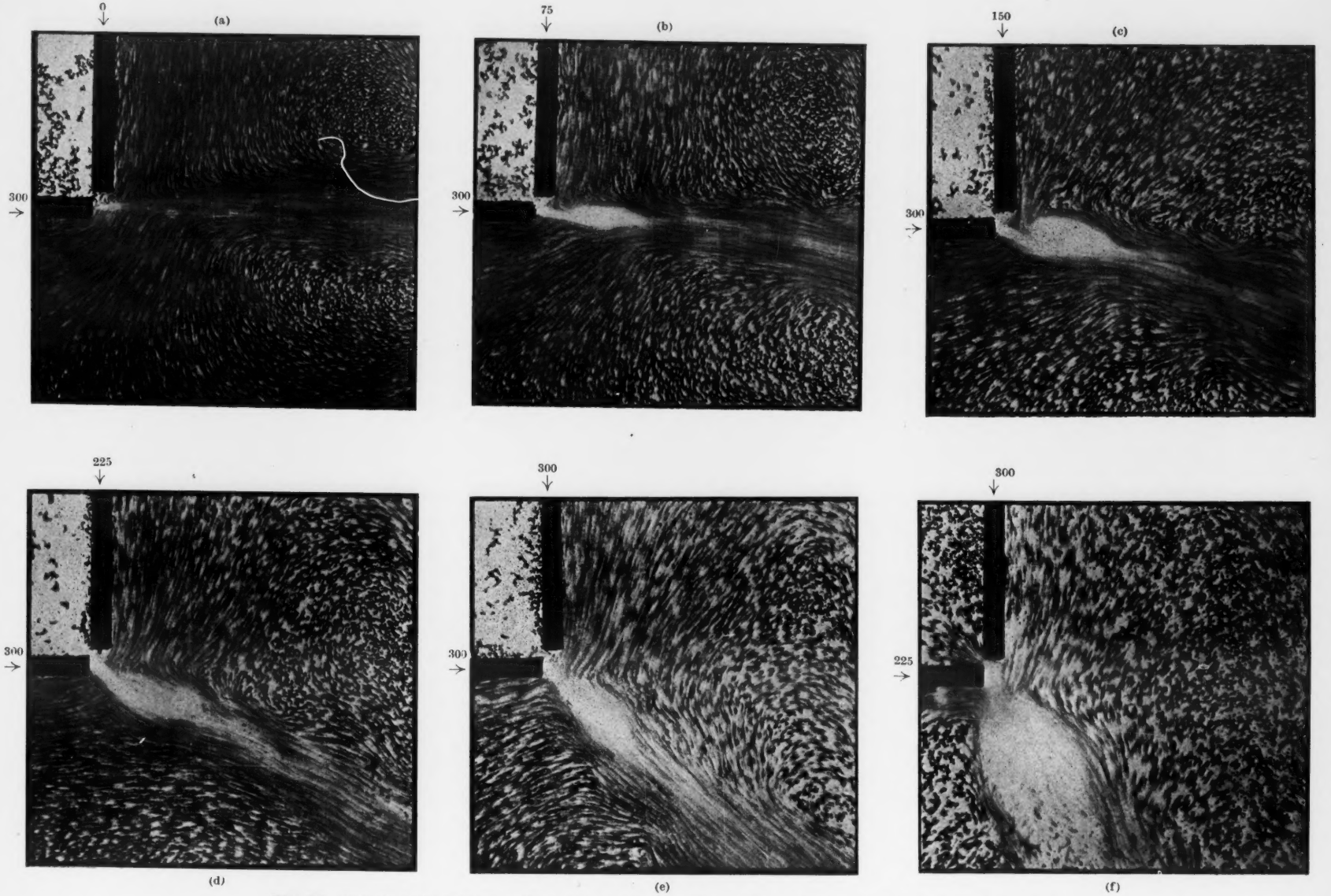

Fig. 22—Jets at right-angles. Effect of varying flow (shown in c.c./min.) on pattern of resultant jet

(Fig. 1). Special precautions were taken to prevent any water that leaked from the trays or ran out over the weirs, from returning back underneath, since this was liable to result in irregular illumination of the geometrical dish. The water was introduced into the model through copper pipes of $\frac{1}{8}$ in. internal dia., fitted in the position shown. It escaped from the models over small copper weirs, whose height was adjustable. Levelling screws were fitted and a spirit level was used to check that the dish was horizontal before any tests were commenced. The flow speeds were measured by means of rotameters, and screw clamps adjusted the flows to low, medium, or high rates, corresponding to 300, 600, or 1000 c.c./min. Given these elementary precautions, it was found that the general pattern was reproducible, although there were always variations in detail, the precise pattern at any given instant never occurring again.

Visualization of Flow

Various methods were tried for visualizing the flow, for example, the introduction of special dyes or of potassium permanganate crystals. Dyes suffer from the limitation that with such high turbulence the whole of the area outside the main jet becomes coloured almost immediately after the dye injection. Permanganate was found to be very suitable for slow flows, but again gave too general colouring with high degrees of turbulence. Aluminium powder floating on top of the water has been used by many workers, for example in the flow round aerofoil sections, but for the present work graded bakelite powder gave the best results. Being both opaque and black, it possesses the advantage that tests can be carried out in broad daylight ; the photoflood lamps were switched on and the camera shutter was operated only when the particular flow pattern being studied had been set up. It has been suggested that patterns obtained in this way are unduly influenced by the proximity of the perspex dish. Although the dish is bound to have an effect on the result, owing to surface tension, it can be stated that two essentially similar patterns are obtained when permanganate is used to trace the flow close to the bottom of the dish and when a floating tracer is used at the top. In all present work the patterns were studied with a water depth of approximately $\frac{3}{8}$ in., obtained by suitable adjustment of the exit weirs.

Results

A large number of different flow patterns have been studied and some hundred or more of them have been photographed. Figures 2 to 22 are typical of the results obtained, the exact pattern varying appreciably from moment to moment and also with the rate of flow and the precise location and size of the jet.

Triangular Dishes

Figures 3 to 6 are typical of the patterns obtained when a jet of water enters a triangular dish at the point shown by the arrow and leaves over a weir or weirs at the point or points shown. In the simplest example, Fig. 3*a*, it will be seen that the jet entering at one corner of an equilateral triangle along the bisectrix, crosses the tank and then divides into two approximately equal streams. Each of these in turn divides again, part leaving the dish over the two weirs and the remainder returning to the root of the jet. This recirculation, which results from the entrainment of the surrounding liquid by the central jet, is characteristic of all the patterns examined, though its nature changes with the particular arrangement under consideration. Figures 3*b* and 3*c* show that there is no great change in the fundamental pattern with increased flow rate, although the amount of dead space is considerably reduced ; neither is the fundamental pattern greatly altered by closing one of the weirs (Fig. 4), recirculation still occurring on both sides of the jet. A dead space, however, will be observed in the corner nearest to the blocked weir.

If a jet is projected through the centre of one side and towards the corner opposite, a peculiarly beautiful and symmetrical pattern (Fig. 5*a*) results. The converging sides of the dish appear to stabilize the jet, much as it might be imagined that a jet could be constrained with a pair of hands. Here, again, an increase in velocity (Figs. 5*b* and 5*c*) leads to changes, though the general pattern is still maintained. If the exit is fitted at the corner at which the jet is pointed (Fig. 6), the other corners become relatively dead, though additional eddies are set up in them as the flow rate increases. A comparison of the exit corners of the dishes shown in Fig. 6 is interesting, since it appears that at the low flow rate the jet can get through without undue disturbance, but that at a slightly greater rate of flow there is considerable throttling in the exit section. When the flow rate is increased still further, as in Fig. 6*c*, the eddies present at the medium flow appear to be swept away and the high-velocity jet proceeds almost directly from entry to exit.

Figure 7 shows the effect of using a tangential jet entering parallel to one side of the triangle. It will be seen that the corners are relatively dead, and that the amount of fluid in motion increases greatly with the flow rate. As in the previous examples, a substantial part of the fluid is fed back to the source of the jet, the remainder passing out through the exit. It might be expected that patterns such as those shown in the foregoing illustrations would be radically affected by any roughening of the tray walls. Tests made, however, with corrugated strip inserts placed along the walls (there being 24 corrugations per side) resulted in surprisingly little change in flow pattern, whether the jet was introduced along a bisectrix or parallel to one side to give the tangential type of pattern. A photograph of the flow obtained with a corrugated tank is given in Part III (*see* Fig. 51*a*).

Semi-Circular Dishes

A great variety of patterns can be obtained with semi-circular dishes, according to the position of the entry and exit points. Figures 9*a* and 10*a* show what happens when a jet passes from the centre of the arc to the centre of the circle and *vice versa*, with exits at the corners or part way along the sides, while Figs. 9*b* and 10*b* show the corresponding patterns for higher flow rates. The return feed is quite obvious in Fig. 9*a*, but not so obvious in Fig. 10*a*, except at

the root of the jet. This recirculation is even more remarkable when viewed visually, since particles of bakelite can be seen to come to the very edge of the weir and then to return to the root of the jet from which they first came. Figure 8 shows the effect of using differential flow rates in a twin-jet system. The influence of the second (slower-speed) jet in Fig. 8*b* on the original flow pattern, and the roughly symmetrical pattern obtained when the flow rates are equal (Fig. 8*c*), are of particular interest. The most interesting feature of this pattern is the extraordinary distance which much of the fluid traverses before leaving the dish. Bakelite entering at the source of the left-hand jet may recirculate one or more times on the left-hand side and then become entrained by the tip of the jet on the right-hand side, recirculating to its base and only subsequently passing out with the original feed water from the right-hand jet. A similar phenomenon is observed in Fig. 12, where the fluid in the lower jet goes a distance of approximately two diameters before becoming entrained at the base of the higher jet, from which it is taken to the exit at the middle of the semi-circle. Figure 11 shows the effect of two jets at an angle to one another with exits at the end of the diameter.

Ellipsoidal Dishes

Figure 13*a* is very characteristic of the type of pattern obtained with an ellipsoidal dish. It will be seen that the pattern existing at the time the photograph was taken was highly asymmetrical, although the general arrangement of jet and exit is symmetrical. Still more peculiar was the fact that this particular type of asymmetry was maintained at higher flow rates (Fig. 13*b*). Indeed, it can be stated quite definitely that the patterns existing in ellipsoidal dishes are peculiarly unstable. It might be imagined, for example, that if a jet were pointed along a major axis and the exits were located symmetrically on either side of the ellipse, the water would proceed to the opposite side, divide, and return to the two exits. This condition, which is approached in Fig. 14*b*, is rarely maintained for more than a short time. The normal condition is one in which the jet swings from such a central position either to the left or to the right, until almost the whole of the water floods out through one exit while the other is practically starved. With certain conditions it is found that the jet will swing from one exit to the opposite exit through the central position (Fig. 14) with almost pendulum-like regularity. If the jet is introduced along a minor axis, as in Fig. 15, a similar asymmetry is observed.

Figure 16 shows the effect that is observed with opposing jets and central exits at either side. It might be expected that with such conditions the flow pattern would consist of two cones, base to base, with symmetrical flow to the exits on either side. This condition has never been observed in the authors' experiments, the patterns shown in the above illustrations being typical of what is normally observed. In Fig. 16*a* the two jets are side-by-side, though by no means independent one of the other, the feed water from one providing the entrainment for the other. Figure 16*b* shows a completely asymmetrical arrangement, while Figs. 16*c* and 16*d* show patterns that are more or less symmetrical but with respect to two different axes. None of these patterns persists for any length of time.

Circular Dishes

Figure 17 shows the effect of directing a jet across the diameter. The pattern set up is the elementary one already referred to as that obtained when soup enters a spoon. Incidentally, use has recently been made by Fossett and Prosser[35] of a similar flow pattern, in the jet mixing of tetraethyl lead in large petrol tanks. Figure 18 shows the effect of using tangential jets and a central exit. A comparison of the annular flow with the small amount leaving by the central exit, suggests that the volume of liquid in motion is far greater than that entering the system. The two patterns shown in Fig. 19 are very similar to those shown in Figs. 16*b* and 16*c* for ellipsoidal dishes.

Square Dishes

When the jet is shot across the dish towards the corner (Fig. 21) a particularly stable pattern is set up, similar to those shown in Figs. 5*a* and 5*b* of the triangular series. Most of the other arrangements give highly asymmetrical patterns, as shown for example by Figs. 20*a* and 20*b*, and by the higher-speed patterns of Figs. 20*c* and 20*d*. It will be noticed that an increase in speed from the condition shown in Fig. 20*a* has led to a reversal of the side on which the main flow occurs, whereas with Fig. 20*b* the change to Fig. 20*d* shows no such effect. This result is characteristic of the fortuitous nature of the patterns obtained with square dishes.

Jets at Right-Angles

Figure 22 illustrates the critical behaviour of jets impinging on one another at right-angles. It will be seen that when the speed of the second jet is increased from low to high, there is at first very little effect on the main jet direction. At a certain stage, however, the equilibrium position is critical, a big swing occurring for a change in ratio of only 3 : 4 to 4 : 3. This observation throws considerable light on the known critical behaviour of the flame in furnaces where the air enters at right-angles to the gas stream.

Two-Dimensional Models of Furnace Details

Figure 2 illustrates how the two-dimensional technique can be applied to the study of certain features observed in three-dimensional models. Reference will be made in Part III to the eddies observed between the front-wall pillars in open-hearth furnace models. It has been suggested from time to time that rounding of front-wall pillars would result in less eddying and, therefore, in less wear. The photographs shown suggest that the eddy would still be present, even with the rounded pillars, though it might be slightly less severe. It is interesting to note the way in which the strength of the eddy falls off with the decreasing speed of the jet as it passes the first, second, and third doors. In actual practice the relative strength of the eddies would be quite different, since the velocities would not necessarily fall off in a similar manner.

PRELIMINARY CONCLUSIONS

Specialists in flow problems will be familiar with most of, if not all, the observations discussed in the previous section, but it may be of help to those less familiar with the field to summarize in simple language the elementary conclusions that can be reached from such experiments:

(1) A fast jet passing through a stationary or slowly moving medium results in entrainment, *i.e.*, the frictional drag between the jet and the surrounding medium causes part of the latter to be carried forward with the jet. This can be observed in all the flow patterns shown.

(2) Such entrainment normally leads to recirculation to replace the material entrained. Expressed in another way, the action of the jet is to produce a low-pressure region round it which is then fed from regions of higher pressure—or even more simply 'nature abhors a vacuum.'

(3) The amount of entrainment increases markedly with the jet speed, as is shown quite clearly in Figs. 5*a* and 5*b*.

(4) Fluid streams behave as though they knew where they were going, *e.g.*, they start to turn a corner before they actually reach it (Fig. 7*a*). This phenomenon is well known in aeronautics. Thus studies of the air in front of a moving plane show that the air starts to move out of the way before the plane arrives. In models such as those described, the phenomenon can presumably be attributed to the survival of the stable form. Thus, water entering an empty tray would not behave in the same manner. It would tend to proceed across the tray until it hit the opposite side. As the tray filled up, however, the pressure distribution might be such as to deflect the jet before actual impact occurred. A full analysis of the conditions set up would at present be quite beyond even the best of mathematicians.

(5) Certain arrangements appear to be inherently unstable, *e.g.*, if a jet is allowed to enter an ellipse from one end along a major axis and the exit flow takes place through weirs on either side, it may be found that the jet will swing from side to side with an almost pendulum-like regularity. At any given moment almost the entire flow may be leaving on one side, the other exit being completely starved. Figure 14 gives examples of the widely different patterns that can appear in even a short space of time.

(6) Certain arrangements, on the other hand, appear to be inherently stable, *e.g.*, the flow pattern resulting from a jet aimed into the corner of a triangle or square along the bisectrix is remarkably steady (Figs. 5*a*, 5*b*, and 21). Any tendency to swing left or right is presumably immediately corrected by an increasing reaction from the closer wall.

(7) The presence of a certain amount of relatively dead space is a major feature of most flow patterns. The amount of this space, or actually the extent to which it is dead, changes with increase in speed until all the water in the dish appears to be in rapid motion (Fig. 7).

(8) Most of the patterns examined are not greatly influenced by flow speed once a turbulent condition is reached (Fig. 3).

(9) Opposing jets frequently give rise to complex patterns, few of which are symmetrical and none of which are the simple 'cone-base to cone-base' type. Examples of the types that can be developed are shown in Fig. 16.

(10) It would appear that when two or more jets enter a dish, one or more of these may reach the exit only after entrainment in one of the other jets, *e.g.*, in Fig. 8*c* the water in the jet on the left reaches the exit only after joining the return flow on the second jet, passing down the second jet and then turning round and coming back to the exit in a direction almost parallel to that of its initial entry. This observation may well be of importance in furnaces, since the designer would scarcely expect that gas entering at a given point might have to travel a distance of ten or twenty times the shortest distance between the entry and exit points before leaving the furnace. Such patterns change continually, photographs revealing the conditions only at any particular instant in time.

(11) Tangential jets in tanks tend to give peripheral flow with considerable dead space in the centre; this is particularly true for low flow rates. An annulus of rotating fluid (Fig. 18) is built up, the thickness of which varies with the rate of feed. This phenomenon has been made use of in the design of tangential-jet type furnaces, such as are employed for heating crucibles.

(12) Jets impinging at right-angles to one another behave in a peculiarly critical manner (Fig. 22). As the flow in the second jet is gradually increased, there is at first little obvious effect on the direction of the first jet. At a certain stage, however, a big swing in resultant jet direction can occur for a comparatively small change in the ratio of the two flows. This conclusion is supported by the critical behaviour observed in furnaces in which the air stream impinges on the gas stream at a relatively obtuse angle.

Acknowledgments

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Part II—FLOW VISUALIZATION AND PHOTOGRAPHY

By R. S. Howes B.Met., and A. R. Philip, M.A.

SYNOPSIS

A description is given of the installation and working of $\frac{1}{24}$ scale model open-hearth furnaces in which water is circulated to represent air and gas. Various ways in which flow patterns through the models have been studied are detailed, together with an account of the photographic techniques employed. Methods have been devised for analysing and interpreting the observed patterns.

PRACTICAL difficulties and the high cost of structural alterations to open-hearth furnaces have made designers reluctant to experiment with major changes in design. Their task has been made the harder by the great difficulty of obtaining scientific data at furnace working temperatures. It is not, therefore, surprising that the development of the open-hearth furnace has been rather slow.

A description is given in Part I of this paper of certain parallel problems that have been successfully attacked by the use of models. Various techniques have been employed, involving measurements of:

(*a*) Pressures and velocities.[9, 22, 38]

(*b*) Mixing[39] (by means of concentration of solutions).

(*c*) Buoyancy factors.[28]

(*d*) Transfer of heat[36, 40] or other physical property.

(*e*) Flow pattern,[32] using some means of visualization.

It was therefore decided:

(1) To build a scale model of an existing furnace and compare its behaviour with that of a full-scale furnace.

(2) To try out design alterations.

(3) To elucidate the fundamental effect of port shape, port size, and geometry of the furnace chamber.

In the present work, flow pattern and mixing rates, involving also the measurement of velocities, were studied. It was hoped that an analysis of flow through a model furnace would reveal unsuspected features that could later be studied on a full scale. Further, this somewhat qualitative approach might be simpler to interpret than strictly quantitative work. Although most work on flow pattern analysis has been carried out on two-dimensional sectional models, the relatively complex arrangement of the ports in an open-hearth furnace rendered a three-dimensional scale model necessary.

The construction and installation of the model furnace is described below, with the techniques devised for visualizing and photographically recording the flow. The procedure employed has already been briefly described elsewhere.[41, 42]

LAYOUT

The model layout represents the checkers, slag pockets, uptakes, and furnace chamber, of an open-hearth furnace, to $\frac{1}{24}$ scale. The checkers and slag pockets are representative of the average size in use in the melting shops of The United Steel Companies, Ltd., so that they may be used for all models studied. On these checkers is mounted the perspex furnace chamber. Air and gas flows are represented by water circulated through the system from a 300-gal. tank by means of a 10-h.p. pump, the separate flows to and from the gas and air ports being metered and controlled. The flows employed are calculated to give similarity as far as possible with the corresponding full-scale open-hearth furnace at the incoming or outgoing ports. Flow is at present studied only within the furnace chamber, but slag pockets, checkers, etc., were built as it was considered that the turbulence set up in these parts (mainly at the incoming end) might affect the flow through the ports and uptakes.

THE MODELS

Figures 23 and 24 show respectively photographs of the models of *K* furnace (Maerz) and *S* furnace (semi-Venturi) at the Templeborough Melting Shop of Messrs. Steel, Peech and Tozer. The constructional drawing of the semi-Venturi model is shown in Fig. 25. This furnace is built of $\frac{5}{16}$-in. sheet perspex sections, the roof sections being moulded to the required curvatures. To resist the estimated water pressures strengthening is introduced by means of heavy $\frac{3}{4}$-in. perspex arches at the furnace knuckles, and by thin stainless-steel leaves at either end of the horizontal central portion of the roof. The sectional assembly simplifies construction and is intended to enable design alterations to be carried out without rebuilding the entire model. The various sections are bolted

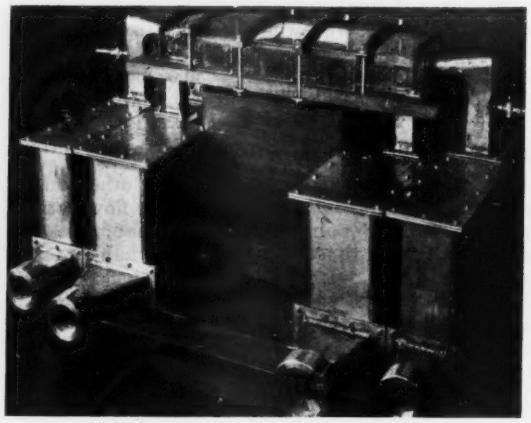

Fig. 23—Maerz furnace model (*K*)

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Mr. Howes is at the Research and Development Department of The United Steel Companies, Ltd., Swinden House, Moorgate, Rotherham.

together with stainless-steel bolts, washers, and nuts, using $\frac{1}{16}$-in. rubber insertion gaskets to ensure watertight seals. End walls are readily removeable for access to the interior of the furnace for cleaning purposes. A Tufnol sheet, 1 in. thick, with an oak overlay, forms the base of the model, the wood surface representing the slag level about 6 in. below the sill-plate. A wooden 'slag surface' is desirable to facilitate fixing banking, 'unmelted scrap,' etc., as required, while the Tufnol base is designed to eliminate the warping experienced on the wooden base of the Maerz model. To assist photography the entire base is painted mat black. In the design of the checkers and slag pockets an attempt was made to simulate all major bends in the corresponding parts of the standard furnace system. Both these and the uptakes are constructed in 8- and 12-gauge stainless steel to withstand the maximum estimated pressures (approximately 3 atm. in the incoming-gas checker). Each checker contains a filling of teak strips (Fig. 26) laid criss-cross in a stainless-steel frame to represent brickwork.

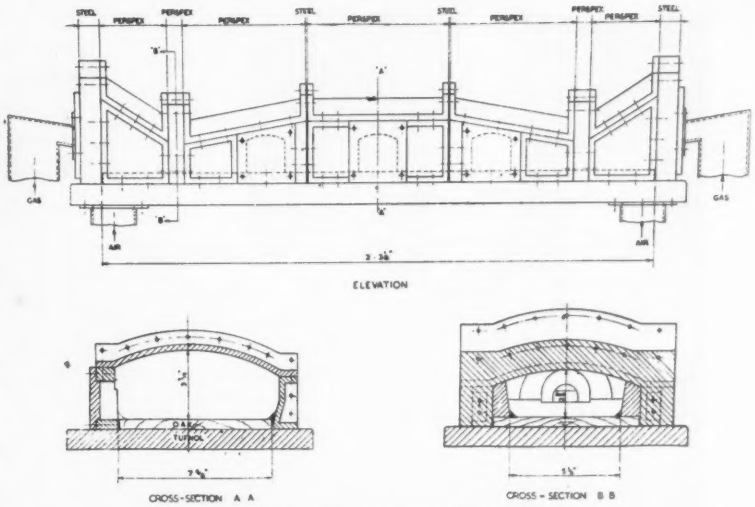

Fig. 25—Construction of semi-Venturi model

HYDRAULIC SYSTEM

The hydraulic system is shown in Fig. 27. Water from the rectangular supply tank is fed by means of a 10-h.p. pump into a 3-in. pipe. This pipe is fitted with a main control valve, and thereafter divides at a T-piece with double elbows into two 2-in. pipes, which feed the air and gas checkers respectively. These 2-in. pipes each contain an orifice plate and valve for metering and controlling the individual flows, the necessary number of diameters of straight pipe upstream and downstream from the orifice being incorporated. At the outgoing end of the furnace system, separate pipes from the gas and air checkers return the water to the tank, each of these latter pipes being also fitted with orifice and valve for metering and control. Owing to the large flow normally going through the outgoing air checker, a 3-in. return pipe was installed from this checker to the tank, as it was not suitable to have an orifice in a 2-in. pipe, capable of metering such flows. The supply tank, normally containing about 250 gal. of water, is fitted with a 2-in. supply and drain, for rapid filling and emptying. This is necessary because of the need for working with very clean water.

Figure 28 shows the furnace and checkers with the ingoing supply pipes, orifices, manometers, and valves, while Fig. 29 shows the tank, pump, main control valve, and return pipes from the model to the tank.

Calculation of estimated head loss through the system suggested that under extreme conditions of operation the pump should be able to deliver 15,000 gal./hr. against a head of 75–85 ft. In practice it has

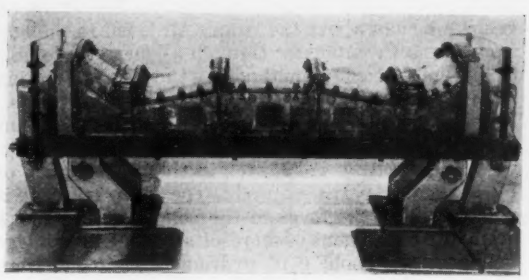

Fig. 24—Semi-Venturi furnace model (*S*)

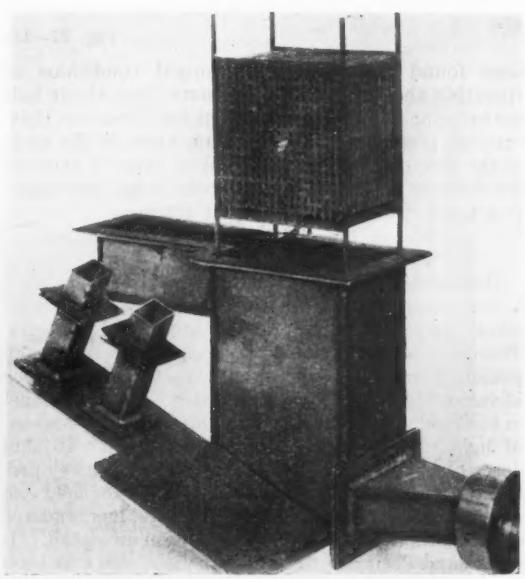

Fig. 26—Details of checker construction

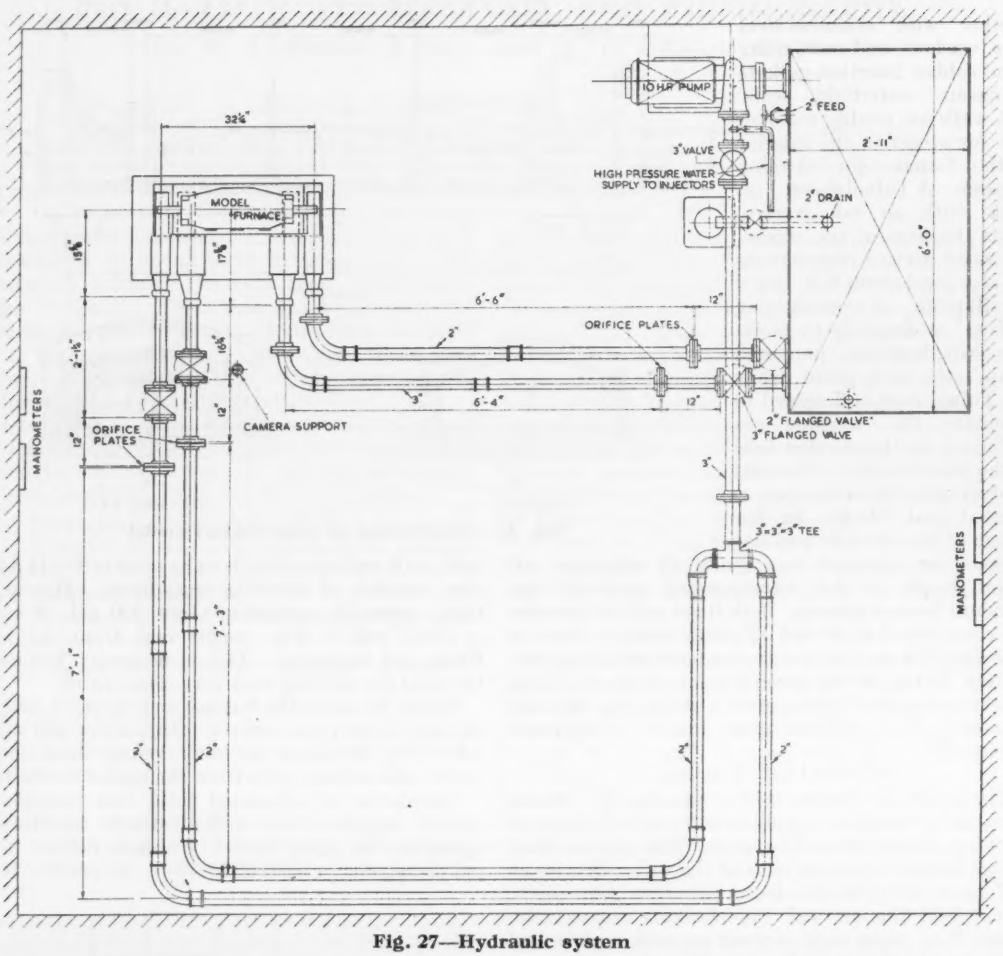

Fig. 27—Hydraulic system

been found that under all normal conditions of operation the head loss is not more than about half the extreme figure. It should be noted, however, that, even so, pressures of about 3 atm. exist on the walls of the incoming-gas checker and of about 1 atm. on the furnace roof, this latter figure being equivalent to a total upward force of about 1 ton.

THE OPTICAL SYSTEM

Illumination of the whole model at one time gives a very confused picture since the flow at different levels may have different direction and velocity. Therefore an analysis of flow pattern is most conveniently made by building up from the pattern seen at various plane sections. Vertical or horizontal planes in the model were therefore illuminated with 'sheets' of light. A technique similar in principle to that described by Fage and Preston[43, 44] has been developed, but the very considerable increase in size of field and particle speed, as compared with theirs, has rendered their method unsuitable for adoption in detail. It was found desirable to employ a light sheet at least 8 in. wide, and to be able to photograph this with exposures as short as $\frac{1}{2000}$ sec. At the same time the complete optical system must be light in weight and very compact, to facilitate manipulation around the model. Eventually the system shown in Fig. 30 was adopted. It consists of an 8-in. double plano-convex condenser, mounted in a light-proof aluminium box, the front of which is fitted with a pair of adjustable shutters to control the thickness of the beam. Behind the condenser, in a detachable aluminium lamphouse, is mounted a 2-kW. lamp with an 8-in. line filament. The lamp is cooled by air entering the base of the box through a diffuser and leaving by a light-trapped ventilating slot above the lamp. Air is fed to the box from a small compressor through a length of flexible tubing. This cooling method has the merit of adding very little to the weight and bulk of the apparatus.

A line source was selected in preference to a point source to avoid the sharp shadows which might otherwise be caused by bolts, etc., in the model walls, or by the tracer particles used. The lamp filament is placed behind the focus of the condenser, so that a gradually convergent beam results, the filament image being formed about 6 ft. in front of the condenser. This procedure, in conjunction with a single slit, was found to produce a sheet of light of almost uniform

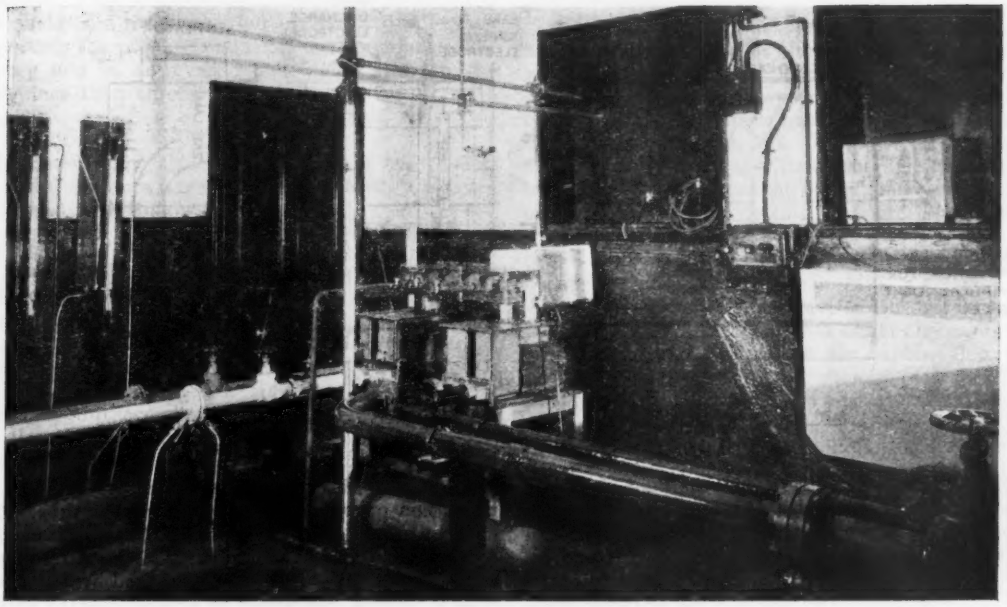

Fig. 28—Furnace supply pipes

thickness over the first 12 in. Normally a slit width of $\frac{1}{4}$ in. is used. To obtain a vertical light sheet, a length of optically flat silver-surfaced mirror at a 45° angle is attachable to the condenser box immediately in front of the slit, so that the light emerging through the slit is turned downwards through 90°. The optical system described above is clearly of low efficiency, but the technical difficulties of constructing a more efficient system would be very great and could hardly be overcome without a considerable increase in weight and size, not to mention expense. It therefore appeared preferable to increase the intensity of the light source as necessary. To avoid distortion due to refraction at oblique surfaces of the model the furnace chamber was surrounded by a rectangular perspex tank, filled with water sufficiently deep to cover the entire model.

The use of the 2-kW. lamp is entirely satisfactory

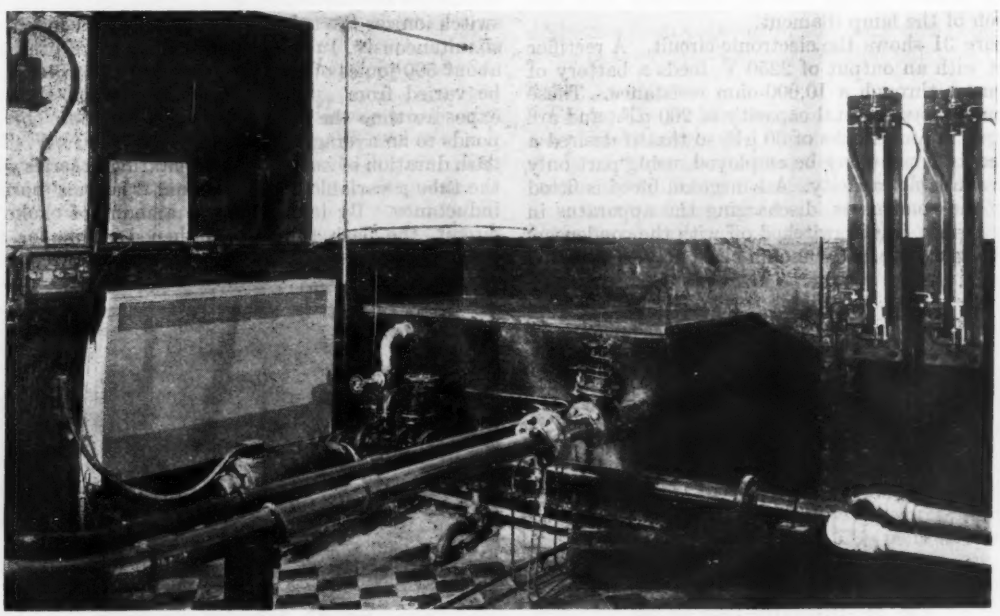

Fig. 29—Pump, tank, and main valve

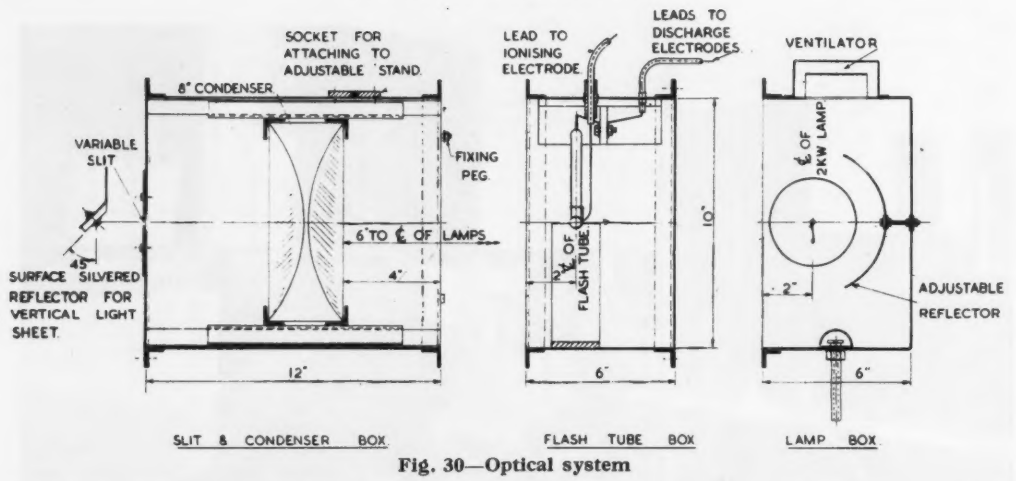

Fig. 30—Optical system

for viewing the flow pattern, but the light output is inadequate for photography. It is found that optimum streak lengths are obtained with exposure times of $\frac{1}{100}$ to $\frac{1}{200}$ sec., whereas with the lamp, exposures shorter than about $\frac{1}{20}$ sec. are under-exposed, even with high-speed film. The difficulty can be partly overcome by overrunning the lamp by applying 400 V. instead of the rated 230 V. momentarily during photography, and in this way exposures of $\frac{1}{200}$ sec. have been made. This, however, is clearly not a satisfactory technique for routine work. Accordingly special flash discharge tubes have been developed for this work.

These special tubes have a straight central portion 8 in. long, the ends containing the electrodes being bent back at right-angles.[1] One such tube is mounted in a rectangular box which can be interchanged with the 2-kW. lamphouse, so that the position of the central portion of the tube is coincident with the position of the lamp filament.

Figure 31 shows the electronic circuit. A rectifier circuit with an output of 2250 V. feeds a battery of condensers through a 10,000-ohm resistance. These condensers have a total capacity of 200 μF., and are arranged in four blocks of 50 μF. so that if desired a smaller flash tube may be employed, using part only of the available capacity. A 1-megohm bleed is fitted across the condensers, discharging the apparatus in about 15 min. if it is switched off with the condensers in a charged state. A 1000-ohm bleed may be switched in circuit to discharge the condensers rapidly for inspection purposes, without flashing the tube. Discharging of the condensers through the tube is carried out by a contactor switch in series, closed by means of a solenoid. The solenoid is energized by a separate (230-V.) circuit, completed by pressing a small button switch. Normally the condensers take about 45 sec. to charge-up after being totally discharged by a flash. The point at which full charge is reached is indicated by a pilot lamp.

The flash tube itself is filled with a xenon–krypton mixture, at a pressure which requires preliminary ionization before the discharge can pass. Such ionization is provided by leading to the centre of the tube a 25,000-V. supply from a small high-frequency coil. The primary of this coil is also wired in series with the operating button of the contactor switch which discharges the condenser block. Thus, depressing one switch ionizes the tube and discharges the condensers simultaneously. In operation the condensers discharge about 500 joules of energy in a flash time which may be varied from $\frac{1}{1000}$ to $\frac{1}{20000}$ sec. Over the shortest exposure time the energy discharge therefore corresponds to an average power output of 1000 kW. The flash duration is varied by incorporating in series with the tube a variable choke of about 2 henries' normal inductance. By increasing the amount of choke in circuit, the flash time is lengthened, while for the longest exposures a 25-ohm variable resistance is also

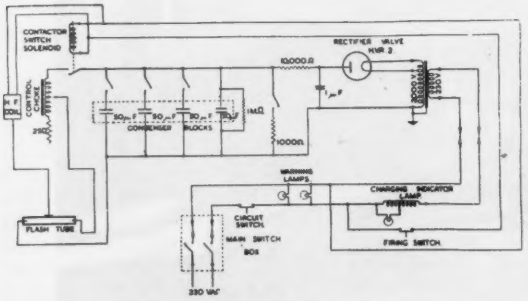

Fig. 31—Discharge-tube circuit

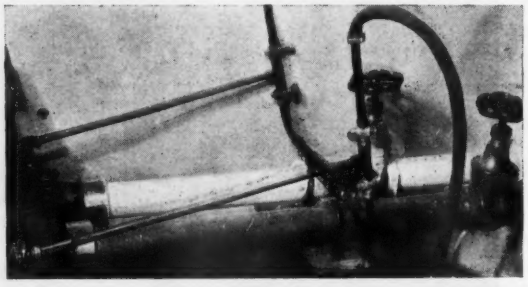

Fig. 32—Injection apparatus

included. Part of the energy is of course absorbed in the choke and resistance, but even with the longest exposures the proportionate loss is not serious. The energy loss is, however, much higher through the resistance than through the choke.

VISUALIZATION

In determining flow patterns within the models several techniques have been investigated ; these are described in the following paragraphs.

Dyes

The method first tried was to introduce dyes of different colours into the air and gas streams at the base of the checkers with the injection apparatus (Fig. 32). A high-pressure water supply was used to force short bursts of concentrated dye into the air and gas streams as desired. However, diffusion of the dye in the furnace chamber occurs much too rapidly for this to be an effective method. An attempt has been made to study mixing, using a similar technique, by adding a solution of sodium thiosulphate to the water in the tank and injecting iodine into the gas stream. This method is promising, but has not yet been developed, partly because of the precautions that must be taken to minimize corrosion by the iodine.

Aluminium

The use of aluminium particles for flow visualization has been described by Fage and Preston.[43] Considerable modifications to their technique were necessary, but this method now produces some of the best flow patterns that have been obtained. Aluminium powder, first treated with a wetting agent, is added to the tank and goes into general suspension in the circulating water. With the first type of particle employed, a fairly good visual pattern was obtained, but photographically the method was a failure (Fig. 33). The aluminium showed up as extremely short streaks, apparently due to the disc-shaped nature of the particles, which change orientation rapidly as they move downstream.

Eventually a grade (GRN) of aluminium powder with approximately spherical particles was adopted, and this gives very satisfactory results (Fig. 34). The concentration normally used is 200 c.c. of powder to 250 gal. of water. The use of aluminium has the advantage that the angle of optimum reflection is about 90° to the incoming light, so that the camera can be placed vertically above the plane on which it is focused, thus avoiding distortion.

This method has the disadvantage that air flow cannot be distinguished from gas flow in the furnace chamber. This was overcome by circulating clear water and injecting aluminium into the gas or air stream separately. The aluminium-laden water leaving the furnace was run to waste instead of returning to the tank for recirculation. The resulting photographs (Fig. 35) are of interest, but the method is not practicable as a routine owing to the excessive water consumption.

With aluminium powder of less than 120 mesh the tendency for particles to sink in passing through the model is negligible at the water velocities employed.

Gas Bubbles

It was found that the flow pattern through the model was apparent in the plane of illumination without any addition of tracer. This is due to the presence of minute air bubbles released at the two control valves, and these bubbles have been utilized for photography (Fig. 36). Their use has, however, two serious disadvantages, firstly there is a large fall-off in light intensity across the model, and secondly, the optimum angle of reflection is appreciably greater than 90° to the beam, so that the camera has to be tilted. Further, it is again impossible to distinguish between ' gas ' and ' air ' flow.

A method has been devised in which tracer bubbles can be introduced into either the gas or the air system separately. The air bubbles described above can be eliminated by restricting the flow with the main valve so that the two separate control valves are kept almost fully open. This procedure is also carried out before the introduction of aluminium powder. Compressed gas, such as air or oxygen, from a cylinder, is now introduced through the injection apparatus. This injected gas appears in the water entering the furnace as a stream of small bubbles which serve as excellent tracers, both for visual observation and for photography (Fig. 37). The rate of flow of bubbles can be controlled so that the most suitable density of pattern for photography can be selected. With this method it is possible to get some idea of the mixing conditions within the furnace.

It is of interest to note that Fage and Preston[43] experimented with a similar method but with little success owing to the rapid rise or absorption of the bubbles in the water. In the present work, success is due to the relatively high water velocities employed, in comparison with which the rate of buoyancy rise of the bubbles is insufficient to affect materially the observed pattern. In practice, patterns using lighter-than-water bubbles as tracers show no obvious difference from patterns of the same flow conditions using heavier-than-water aluminium particles.

Other Techniques

The possibility of using other means of visualization has not been overlooked. For instance, should detailed study of slow-moving parts of the flow be desired, the use of thin tracer filaments of dye might be useful. Over most of the furnace, however, turbulence is likely to be too great to permit of good results with this method. In this connection, tests appear to show that certain fluids, such as milk or ' Dettol,' which have been used by some workers, have little or no real advantage over dye. A development of this technique now being considered is the injection under pressure of a fine jet of creosote. Such a jet breaks up into minute globules which can be readily photographed.

An alternative to the tracer filament technique would be to fix short lengths of cotton thread inside the model to act as ' wind-socks.'

A method somewhat allied to the foregoing is the use of oil globules as tracers. This method has been described in detail by Walker[45] and is also mentioned by Fage and Preston.[43] For precision work at low flows this technique has the advantage that an oil

mixture can be prepared of the exact density of water. It does not, however, appear adaptable to work on the present scale as it involves nearly 300 gal. of water and highly turbulent flows. The globules require great care in preparation, even in small quantities, and soon start to coalesce.

An experimental run, using 'Bemax'[46] instead of aluminium, has also been carried out. It appeared much inferior to aluminium owing to its low reflectivity.

Finally, mention should be made of the use of polarized light in connection with bi-refringent colloidal solutions or suspensions of vanadium pentoxide,[47] bentonite,[32,48] or other material.[49] This type of flow analysis shows dramatically the regions of small and large amounts of shear in the fluid. Unfortunately it is essentially a two-dimensional technique for laminar flows.

PHOTOGRAPHY

A Leica model III*A* 35-mm. camera and a Stewartry copier are used for the recording. In order to photograph any plane, horizontal or vertical, in the furnace, both the camera and the lamp system must be capable of being sited at any position around the furnace. This is achieved by means of the adjustable stand shown in Fig. 28. The stand consists of a 2-in. dia. steel tube grouted into the floor, about 2 ft. in front of the 'centre door' of the model. The top of this column is attached to angle irons fixed into the wall of the room, for additional rigidity. The column carries two sliding horizontal arms, which can be clamped in any position, and each of these arms is fitted with a collar, which again can be clamped as desired. Through each collar passes a vertical screwed rod. Fine adjustment of the height of each rod is obtained by means of threaded locking wheels. The camera and the condenser box are each attached to one of these rods with a ball and socket joint. This arrangement allows of photography of any vertical or horizontal plane in the model, the vertical planes being illuminated with the aid of the 45° mirror previously described.

The camera lens is a 5-cm. Elmar of $f3{\cdot}5$ aperture. Focusing is carried out on the ground-glass screen of the copier, using the 2-kW. lamp as illumination. Thereafter the flash tube is substituted for the lamp, and the camera for the ground-glass screen, and an exposure is made by opening the camera shutter in darkness and then discharging the flash tube. Most of the photography has been done on Ilford *FP*3 film, developed in Kodak *D*76 developer at 65° F., and given 50% over-development to increase contrast. Very good results have recently been obtained with Ilford recording film 5*G*91. This film is much faster than *FP*3 when used with the flash tube, and it has a higher contrast, but is not of such fine grain. Owing to shrinkage, ordinary bromide paper is unsuitable for producing positives on which streak lengths, etc., are to be measured; for this latter purpose Kodak waterproof bromide is used. In the production of positives, the fall-off in light intensity with distance from the slit becomes noticeable. To obtain a more uniform print, very careful shading during exposure in the enlarger is necessary. It should be noted that the fall-off in light intensity varies appreciably with the nature of the tracer employed, *e.g.*, aluminium or air bubbles. This trouble is aggravated by even slight amounts of dirt in the water.

It was thought that varying light intensity across the model might have the serious effect that the side nearer the light source would not be comparable with the farther side because of (1) diminishing 'contrast' on a print with increasing distance from the light source; and (2) shadows cast by tracer particles near the light source reducing the effective number of particles farther from the source. In practice neither of these factors has proved important, the second no doubt being partly overcome by the use of a line source. However, as a precaution, all flow surveys are carried out illuminating both from the front and from the back of the model in turn.

Photographs have been taken using two successive flashes on the same negative, the flashes being given from opposite sides of the model. This still did not produce even illumination, and although the variation in light was much less, the photographs were otherwise unsatisfactory.

Photographs taken with the discharge tube have the advantage over those taken with a continuous light source, that the direction of movement of the particles is shown. The light intensity during a flash rises rapidly to a maximum and then dies away gradually as the charge on the condensers decreases. As a result, the track of an air bubble or aluminium particle appears to taper to a point in the direction in which it is moving. In the study of highly turbulent flows this feature is a great asset.

In normal working, using air bubbles as a tracer, two photographs were taken at each position. The first was a 'long' exposure of approximately $\frac{1}{130}$ sec., to show direction and velocity of flow by means of streak lengths. The second was a 'short' exposure of approximately $\frac{1}{2000}$ sec., in which all motion of the bubbles is 'frozen,' except near the incoming-gas port. Such a photograph consists of a large number of spots, from the distribution of which a measure of the mixing within the model may be obtained. In this case a tracer is introduced into one system at a time.

With exposures longer than about $\frac{1}{100}$ sec., it becomes increasingly difficult to measure streak lengths on a photograph, owing to blurring and overlapping of streaks. This overlapping effect, however, results in more striking patterns in the photographs as it accentuates such features as vortices. For this purpose exposures of $\frac{1}{20}$ to $\frac{1}{60}$ sec. are most suitable. Very promising photographs of this type have been produced recently by developing to finality to obtain maximum contrast and threshold speed of the film.[50] The exposures are made on Kodak Panatomic *X* film, using the 2-kW. lamp, not overrun, so that with exposure times of, say, $\frac{1}{30}$ to $\frac{1}{60}$ sec., the negatives would be considerably under-exposed if processed normally. With this technique the resulting negative image shows a high degree of contrast, and excellent prints can be obtained (Fig. 38).

A light sheet of the required intensity could not conveniently be obtained wide enough to illuminate at once an entire model about $2\frac{1}{2}$ ft. long. It is

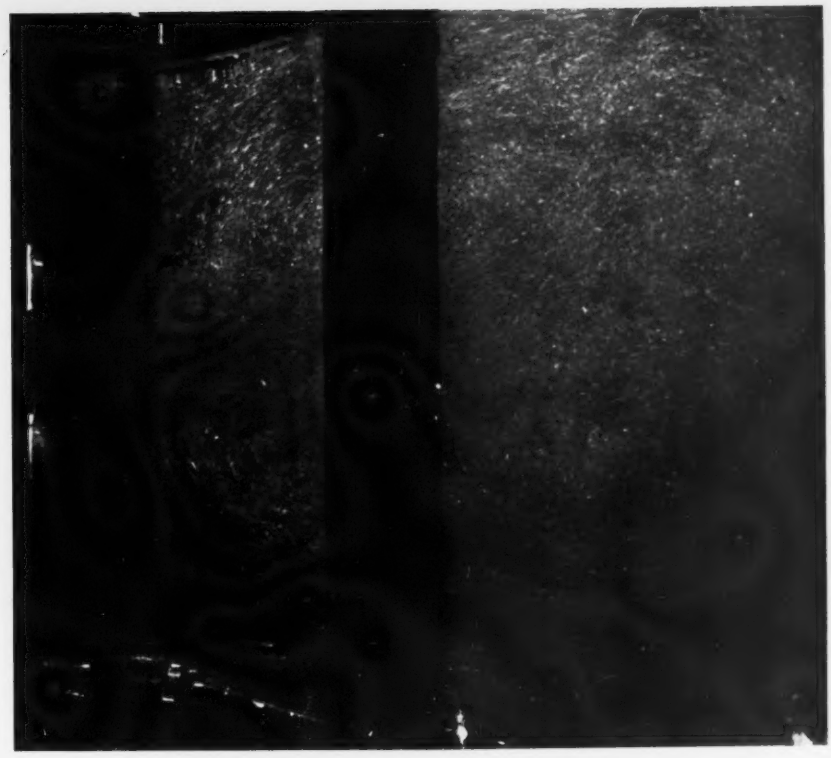

Fig. 33—Flow pattern using lamellar aluminium powder

Fig 34—Flow pattern using spherical aluminium powder

[*Howes and Philip*
[*To face p.* 398

Fig. 35—Flow pattern using aluminium powder injected in the gas stream

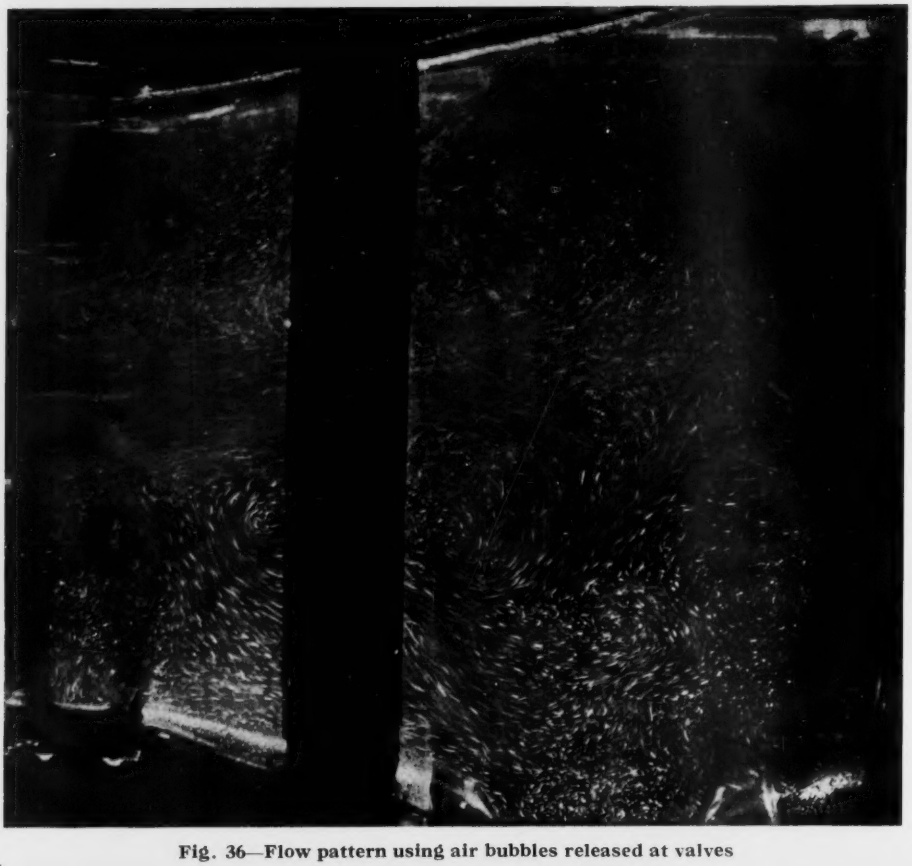

Fig. 36—Flow pattern using air bubbles released at valves

Howes and Philip]

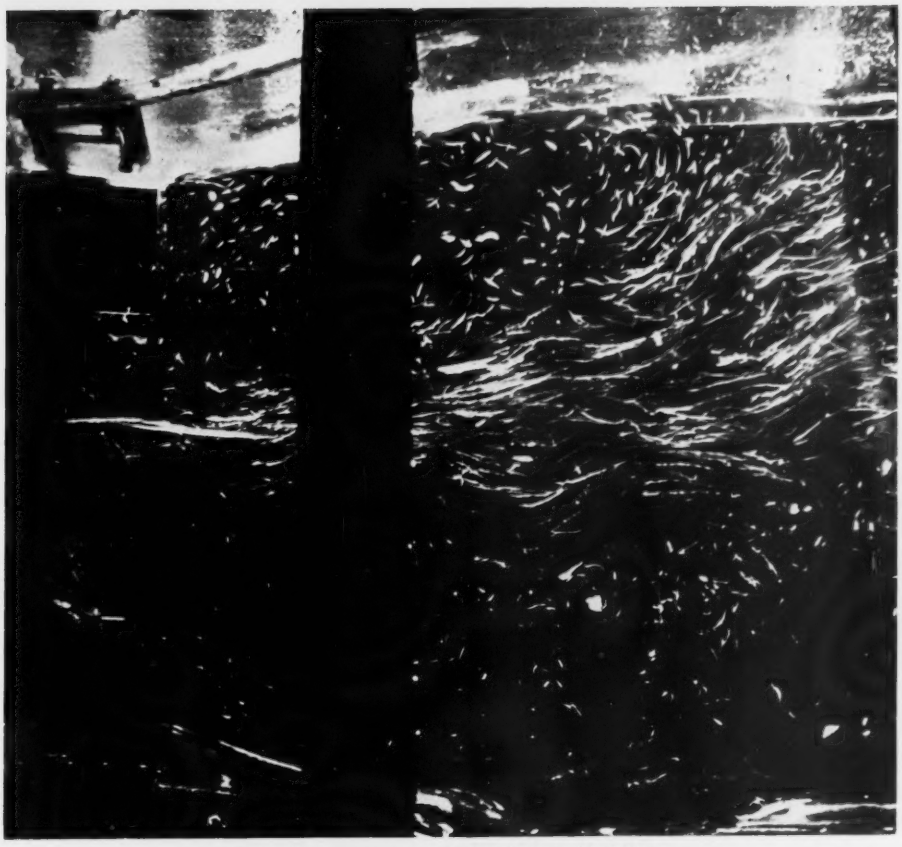

Fig. 37—Flow pattern using injected bubbles

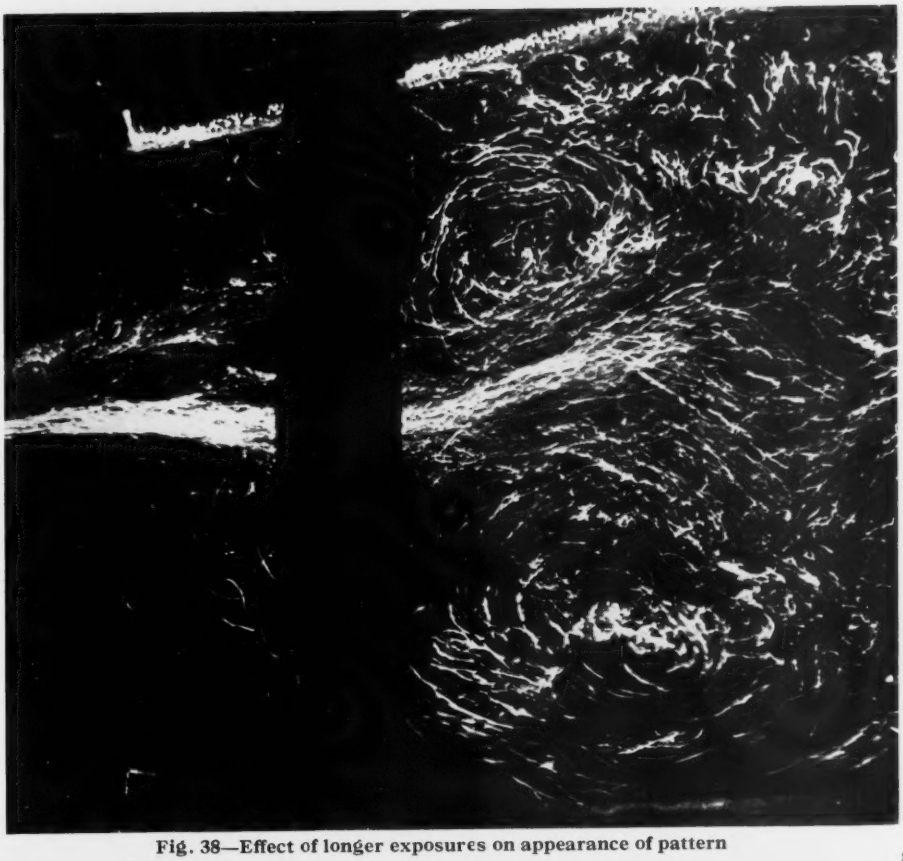

Fig. 38—Effect of longer exposures on appearance of pattern

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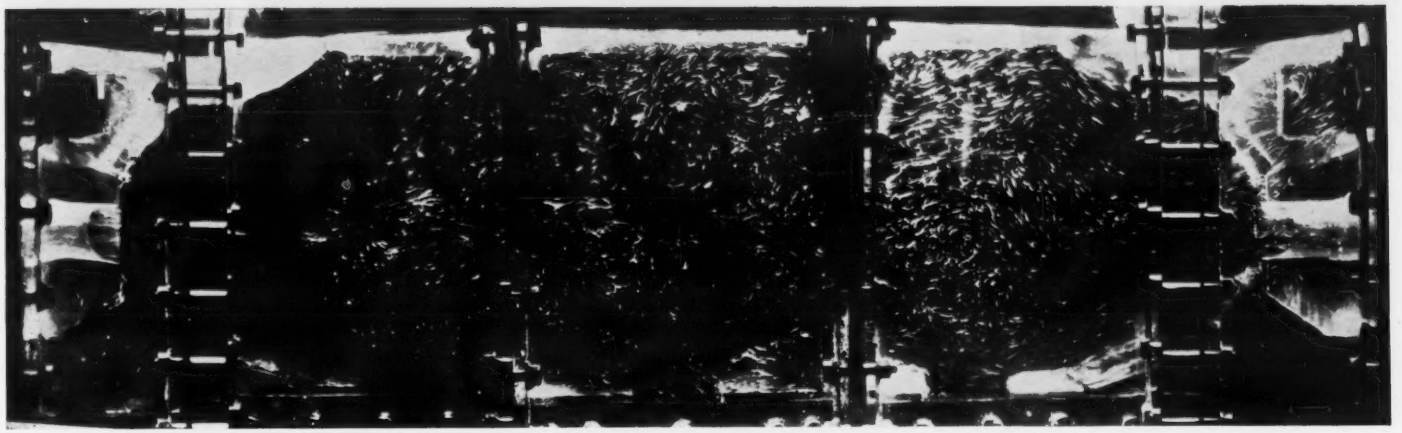

Fig. 39—Composite photograph of flow through semi-Venturi model

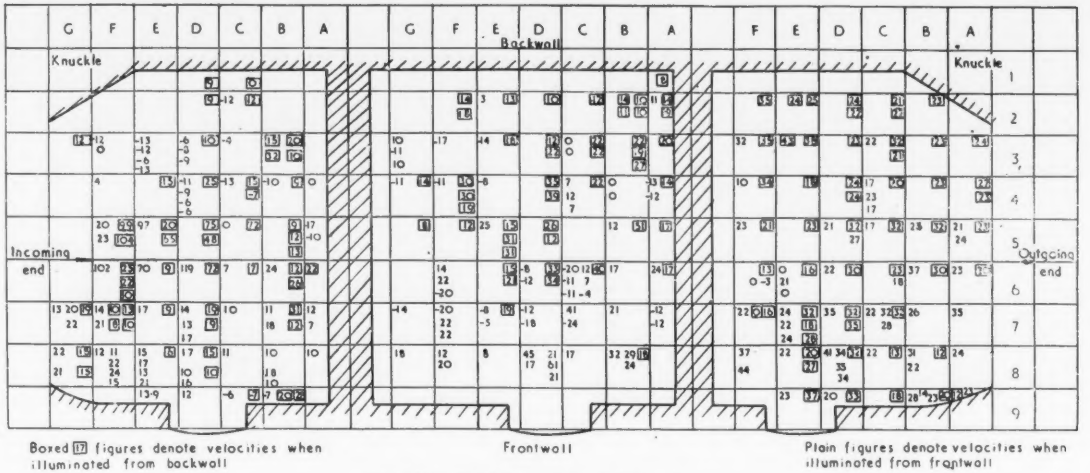

Fig. 40—Grid diagram of Fig. 39

consequently necessary to photograph any plane along a model in portions, *viz.*, incoming end, centre, and outgoing ends. Flow is therefore shown on composite photographs built up from three or five exposures made in the plane of flow. When using bubbles as pattern tracers the camera must, as already mentioned, be somewhat oblique to the plane of light. This introduces a distortion of distances in the photographs, the scale of magnification varying across the model. This effect is not unduly noticeable when the degree of enlargement along the furnace centre-line is the same for all portions. In measuring streak velocities, the effect can be allowed for. Photography of a ' plane ' in portions has the advantage that the light sheet can be tilted when desirable, *e.g.* following the varying slopes of a furnace roof. Thus a photograph showing ' plan at roof level ' is a composite of three or five portions, each of which is an exposure with the light sheet as nearly as possible following the roof slope of that portion. Such an arrangement is much more useful than a simple plane section through a model. In the semi-Venturi design, for example, if a strictly plane section at ' roof level ' were to be made, the level selected would have to be the height of the knuckle to include the entire furnace. The pattern shown would bear no relation to flow under the central portion of the roof, or up the ramps. Success of the ' composite photograph ' technique depends largely on the observed fact that, although individual particle positions and velocities are continually changing with minor pattern fluctuations, the general pattern tends to persist. In the case of major pattern fluctuations at the outgoing end of a furnace, several exposures may be desirable.

MEASUREMENT OF FILMS AND REPRESENTATION OF DATA

Preliminary attempts have been made to use the photographs to determine velocities. The method adopted is to measure streak lengths and directions on the photographs, having regard to certain special considerations. For this purpose it is necessary to know accurately the duration of the discharge-tube flashes for various choke settings. Calibration was carried out using the flash tube as light source to photograph a spinning disc about 12 in. in dia., driven by a synchronous motor. A tachometer was used to check the motor speed. The disc was coated with non-reflecting black velvet paper with one strip of white paper, $\frac{1}{25}$ in. wide, attached along a radius. The camera was placed directly opposite the centre of the disc, about 4 ft. distant, with the flash tube as near as possible to the camera so as to give even lighting. Measurement of the length of blur on a negative caused by the paper strip during a flash enables the effective exposure time of the tube with the selected choke setting to be calculated. Repetition of a calibration shows no appreciable variation in flash time, provided that the condensers are always fully charged before firing. At some intermediate choke settings, double flashes were disclosed and these positions have been avoided in all photographic work. With the longest flash times the gradual die-away of light intensity makes the exact definition of the end of a flash increasingly difficult.

A choke and resistance setting to yield a flash time of $\frac{1}{1300}$ sec. was adopted as standard for model photography. This selection was made because :

(1) Optimum flash lengths for visualizing flow pattern under the conditions of the present work lie between $\frac{1}{100}$ and $\frac{1}{150}$ sec.

(2) With this setting there is no secondary flash.

(3) Although the setting yields one of the longest flashes, the duration can still be measured fairly accurately.

In measuring streak lengths, certain points must be borne in mind : Firstly, only the component of velocity in the plane of the light sheet can be obtained by this means. To determine the component perpendicular to this plane a second photograph is necessary with the light sheet turned through a right-angle. This procedure has, as far as practicable, been carried out. The velocity component in the plane of light can be further analysed into two parts, *e.g.*, for a plan section of the model, into ' downstream velocity ' and ' transverse velocity.' For flow through a simple channel the mean downstream velocity would represent the flow rate, while the transverse velocity would indicate the degree of turbulence. Flow in an open-hearth furnace is complex and of varying direction, so that this simple criterion does not hold. Visual examination of flow through a model furnace will indicate the general direction at any point and the plane in which the principal velocity component at that point will lie. In other words, study of velocity measurements is best carried out with prior knowledge of the general flow pattern as background.

Secondly, the motion of a tracer particle represents, not the motion of an individual molecule of fluid in the model, but the resultant motion of a large number of fluid molecules. A particle thus traces a path somewhat intermediate between that of the comparatively random motion of a molecule and that of the overall mean flow, a feature probably much to the advantage of the technique, since both mean flow and turbulence can be assessed. An approach to this problem on a statistical basis has recently been made.[51]

Thirdly, tracer bubbles may not be illuminated for the whole of the duration of the flash. For example, a fast moving bubble may be situated above the light sheet at the start of the flash, it may move down and through the light sheet, and it may continue some distance below before the flash ends.

On consideration it was realized that with a light sheet inclined at a large angle to the general flow direction the errors due to this effect would probably be so serious as to render the method useless. However, with the general flow direction in or near the plane of the light, errors from this cause are sufficiently small to allow comparisons of velocity to be made. For this reason, all velocity measurements have been made on photographs of sections along the length of the furnace. It must be noted that mean velocity, as measured on the model, tends to be too low, and the error probably increases somewhat with increase of velocity.

Fourthly, for an accurate statistical analysis of velocities, a number of photographs would be required of each section studied, because of the limited number

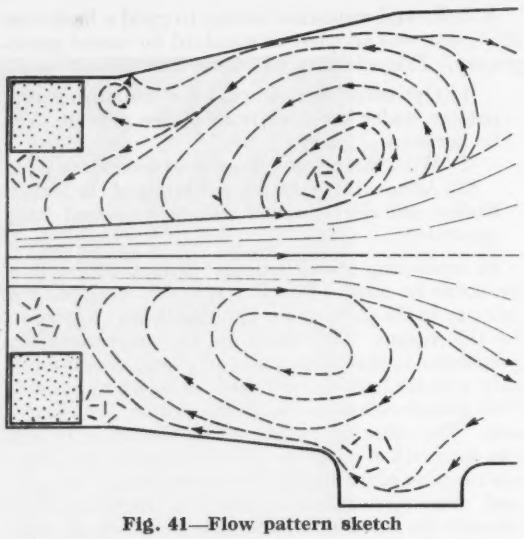

Fig. 41—Flow pattern sketch

of measurable streaks normally found on any one negative; for such an analysis the following points should be considered:

(1) It would not be possible to obtain directly equivalent velocity figures for the full scale, owing to neglect of combustion and buoyancy in the model. It seems possible to find equivalent full-scale velocities with fair accuracy near the incoming and outgoing ports. This question is discussed more fully in Part III of this paper.

(2) From a few photographs a rough estimate of the general magnitudes of the velocities can be made. As it is most desirable not to strain the interpretation of the model technique by suggesting quantitative results which have in fact no counterpart in the full scale, it is probably best to use velocity measurements only as indications of the general order of the gas speeds likely to be met in the full-scale furnace.

Figure 39 shows the flow pattern through the semi-Venturi model at a height about mid-way between bath and roof, with illumination through the back walls. All possible streaks shown in this figure have been measured, and their corresponding velocities have been determined. Downstream and transverse components of the velocities have been separately computed, and the downstream components, converted into approximately equivalent full-scale velocities, have been plotted in the grid diagram (Fig. 40). This procedure has been repeated with the corresponding flow photograph illuminated through the front wall, and the figures obtained have also been included in Fig. 40. A velocity is plotted in the grid square in which the tracer point is situated at the start of the flash. Conversion of measured model velocities to equivalent full-scale velocities assumes a temperature of 1350° C. for incoming gas and air, and 1650° C. for outgoing waste gas, but it neglects combustion.

A more detailed discussion of results is given in Part III, but the following points may be noted:

(1) A study of Fig. 40 suggests that the absorption of light in passing through the model does not materially affect the length of streak obtained from a particle of given velocity.

(2) Velocities measured in the gas stream opposite the incoming door vary from 65 to 119 ft./sec.; these agree well with previous measurements on colour film[1] (*loc. cit.*, p. 149), when gas velocities of 56, 75, and 90 ft./sec. were noted on the full scale. In the latter experiments, gas flow was at the rate of about 320,000 cu. ft./hr.,* as compared with a flow through the model equivalent to 350,000 cu. ft./hr.

In addition to photography, it has been found useful to represent the flow pattern in plane sections by means of sketches. This method has the advantage that in a sketch it is possible to simplify the pattern very considerably to show up the essential features. A sketch, therefore, is of considerable assistance for descriptive purposes, especially for the benefit of those who have had no opportunity of viewing the model in operation, and who may have difficulty in appreciating the full significance of a photograph. Figure 41 is a typical example.

Interpretation of results obtained by any of the methods so far discussed is complicated by the fact that the flow patterns through the furnace are essentially three-dimensional, whereas only two-dimensional plane sections can be photographed or measured. In practice, a rapid survey of the model with a moving light sheet enables a mental picture of the flow to be built up much more dramatically than can be deduced from the study of a photograph or even a series of photographs. To provide a simplified demonstration of the principal flow features, three-dimensional wire models have been constructed. Flow consisting predominantly of gas, air, or waste gas, is indicated by lengths of bell wire of different colours. It is not, of course, possible to define exactly the limits of the various constituents, and a certain amount of judgment must be used in the construction, the underlying object being to show in three dimensions the significant features of the flow through each design with the greatest possible simplicity. Figure 42 is a photograph of one such model (the standard Maerz design). The base and 'end walls' are of wood, the hearth outline being painted on the base. A perspex cover is fitted to preserve the wiring from damage.

CONCLUSIONS

The work carried out has shown that there is no insuperable difficulty in studying flow patterns in three dimensions, but that appropriate special means must be devised for measuring and interpreting the

* All air and gas flows quoted are at N.T.P.

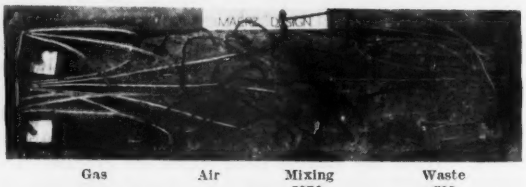

Fig. 42—Wire model of flow in Maerz furnace

results obtained. In the case of the present work, a variety of techniques has been employed, each with one or more distinctive features, and it is hoped to make use of other methods as the work proceeds.

Acknowledgments

The authors' thanks are due to Mr. F. H. Saniter, Director of Research, The United Steel Companies, Limited, for permission to publish this work, and to the Open Hearth Advisory Committee of The United Steel Companies, Limited, for continuous interest and guidance. The authors also wish to thank Mr. M. W. Thring, of The British Iron and Steel Research Association, and Dr. E. J. Gooding, of the Rockware Glass Syndicate, Ltd., for their valuable help in the initial stages; the Triplex Safety Glass Company, Ltd., who constructed the Maerz model; Mr. A. Jollie, of Messrs. Steel, Peech and Tozer, who kindly arranged the construction of the semi-Venturi model; Mr. A. Fage, of the National Physical Laboratory, for valuable advice on several occasions; Mr. H. E. Dall, of Messrs. George Kent, Ltd., for help in water-circuit design; and many colleagues in the Research and Development Department for their valuable assistance.

The flash discharge tube with variable flash times was specially developed for this work by Mullard Electronic Products, Ltd. Likewise, co-operation over a long period was received from the English Metal Powder Co., Ltd., in the search for a satisfactory grade of aluminium powder. For help from these firms and in lesser degree from several others, the authors are most grateful.

Part III—FLOW PATTERNS IN MODEL FURNACES

By I. M. D. Halliday, B.Sc., A.R.T.C., and A. R. Philip, M.A.

SYNOPSIS

The extent to which flow through a water model of an open-hearth furnace is comparable with flow of gases through a full-scale furnace is discussed. The flow patterns observed in open-hearth furnace models of Maerz, single air-uptake, and semi-Venturi design are described, together with the effects on the pattern of certain modifications. Comparison is made between flow features observed on the models and certain results obtained during previous furnace trials. Experiments are being undertaken on production furnaces to see how far results obtained on models can be used to predict the flow patterns obtaining in practice.

ALTHOUGH the operation of a gas-fired open-hearth furnace depends primarily on the manner in which the preheated gas and air are mixed, virtually nothing appears to have been published regarding the flow pattern of the gases within the furnace. The precise way in which the gas and air come together and the character of the exit flow from the furnace have not in themselves been studied, and consequently little knowledge is available as a basis for furnace design. A great deal of empirical work has, however, been done, as has been shown by Chesters and Thring[1] in their survey of port design.

Using transparent model furnaces with water flows to represent fuel gas and air, the flow patterns in the Maerz and semi-Venturi designs (Figs. 43 and 44, respectively) have been studied. The models were constructed as $\frac{1}{24}$-scale replicas of *K* and *S* furnaces at the Templeborough Melting Shop of Messrs. Steel, Peech and Tozer, the design and operation of which have been fully described.[1] The effect was examined of certain modifications to both the Maerz and the semi-Venturi designs, and the pattern occurring in a single air-uptake model was investigated. The latter design is based on *L* furnace at Rotherham, the original design for which was suggested by Mr. S. W. Pearson of Messrs. Steel, Peech and Tozer. A similar design was tested by Dr. A. H. Leckie[36] and his co-workers, as part of the programme on a hot model at the works of the Shelton Iron, Steel and Coal Co., Ltd. The principal differences between these three types of furnace are shown in Fig. 45.

THE BASIS OF SIMILARITY

To study the behaviour of a large apparatus by means of a model, it is necessary to choose operating conditions for the model which correspond as nearly as possible to those of normal full-scale working.

The considerations involved in arranging that the flow of gases or liquids in the model approaches similarity of full-scale operating conditions have been fully described,[2, 5, 24, 52–58] and a readable summary of the principles has recently been given by Thring.[59] Examples in which heat transfer is involved in the full scale have been discussed in some detail,[36, 39, 60] and the relationship between flow, with and without combustion, has also been studied.[16, 20, 32] The aim of the present work is to study the flow in open-hearth furnaces, particularly its aerodynamic aspect. The approach to similarity is considered adequate by assuming the principal forces affecting the flow of gases through a furnace to be those due to their inertia and viscosity.

In a model using water to represent the furnace gases, therefore, similarity of flow compared with the full scale is achieved in respect of inertia and viscosity by arranging the Reynolds number to be the same in both cases. The Reynolds number, Re, represents the ratio of the inertia forces to viscous forces in a fluid relative to the characteristic length of the apparatus, and is defined as follows:

$$\mathrm{Re} = \frac{\rho V^2}{L} \Big/ \frac{\eta V}{L^2} = \frac{\rho V L}{\eta}$$

where, in consistent units,
V = fluid velocity
ρ = fluid density
η = fluid viscosity (absolute)
L = a characteristic length of the system.

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Mr. Halliday is at the Research and Development Department of The United Steel Companies, Ltd., Swinden House, Moorgate, Rotherham.

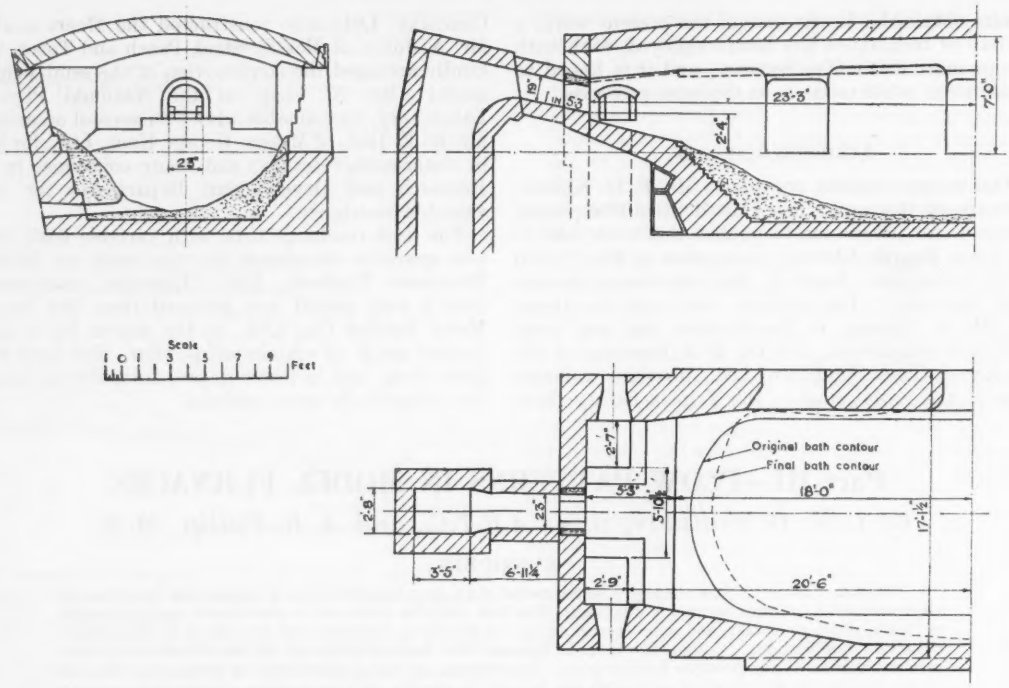


Fig. 43—Port design of *K* furnace, Templeborough. Maerz type

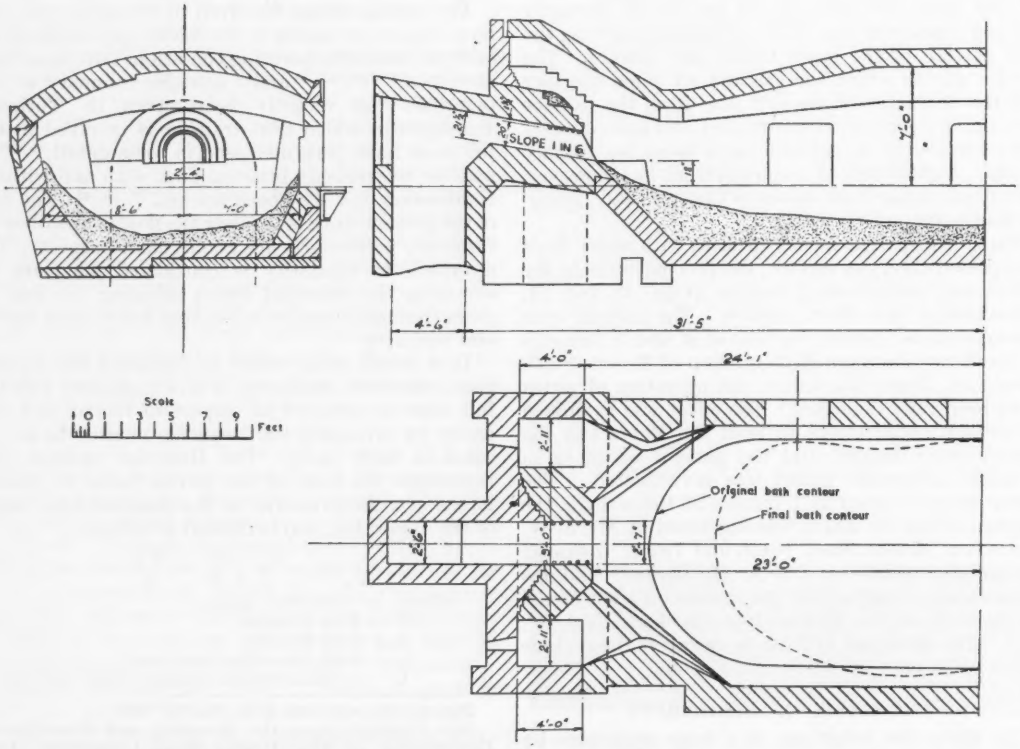


Fig. 44—Port design of *S* furnace, Templeborough. Semi-Venturi type

For any flow condition the numerical value of Re depends on the measurement selected as the characteristic length. In the case of flow through pipes of circular cross-section, the pipe diameter is commonly chosen. With pipes or flues of non-circular section the characteristic length is taken as four times the ratio of the pipe area to its perimeter.

On the production furnaces studied, the Reynolds number for the gas supply at the end of the gas port is of the order of 100,000 at normal working flows. In the models the same Reynolds numbers at the gas port are realized with water speeds there of 15 to 20 ft./sec. Although fairly high, this rate of water flow was practical for routine use (*see* Part II).

Equality of Reynolds number between model and full-scale furnace at the top of the incoming air uptakes or ports is also arranged. In calculations a mean temperature of 1350° C. was assumed in the gas and air ports, the modified Sutherland formula[61] being used to derive the absolute viscosities.

The foregoing assumptions in procedure represent a considerable simplification of the actual position, and lack of similarity has, of course, to be checked. This might be possible by further work, using other factors for the similarity basis, but in any case a final check against full-scale operation is essential.

Some consideration can be given to the extent to which corrections may be necessary to the flow observed in the model. The principal factors excluded are :

(1) Buoyancy at the incoming end, due to a difference in density of the incoming gas and the preheated air.
(2) Change in temperature and, hence, density, and volume of the furnace gases due to combustion.
(3) Alteration of the chemical constituents of the gases due to combustion, including dissociation.
(4) Cold-air inleakage through furnace doors and brickwork.

Buoyancy effects near the incoming end are unlikely to be important, since the density of producer gas does not differ greatly from that of air at the same temperature and pressure (air 0·00129 g./c.c. at N.T.P., and producer gas from coal 0·00113 g./c.c. at N.T.P.).[61] A mean temperature of 1350° C. can be assumed for preheated air entering the furnace, and this results in a density of hot air of 0·000217 g./c.c. At the same preheat temperature the incoming producer gas has a density of 0·000190 g./c.c., but if the preheat on the incoming gas were assumed to be 1150° C. the density of the gas would be exactly equal to that of the air. This somewhat lower preheat on the fuel, as compared with the air, is not uncommon, and in any case it is clear that the buoyancy effect of the gas, if heated within the furnace but without taking combustion into effect, would be very small. In the incoming part of the furnace, say as far as the first door, combustion of the gas stream is not fully developed and furthermore gas velocities are all high (about 100 ft./sec. at full scale, and on the model about 15–20 ft./sec.). Hence it is unlikely that, near the incoming ports, temperature rise or combustion will seriously affect the observed pattern.

In the centre portion of the furnace, combustion is normally developing to its fullest extent, so that the gases associated with the flame will be heating and

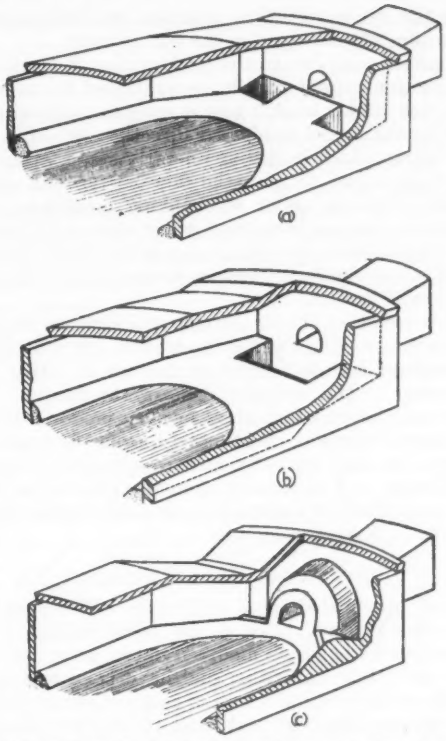


Fig. 45—Gas and air ports of the three furnace types : (a) Maerz, (b) single air uptake, and (c) semi-Venturi

expanding considerably. It is possible that in this portion of the furnace appreciable divergence occurs between the observed flow pattern in the model and the actual flow at full scale. It is intended to check the extent of this divergence later on a production furnace.

Towards the outgoing end of the furnace, combustion should normally be almost complete, so that a reasonable approximation is to assume that the fast-flowing gases near the outgoing ports are homogeneous in constitution and temperature. Thus, in this portion, buoyancy considerations will probably not necessitate any large corrections to the observed flows in the model. It is to be noted, however, that flow at the outgoing end of the furnace will be affected by prior flow through the central portion, in which the divergence between model and full scale may be considerable.

As the outgoing gases are considerably hotter than the incoming gases, the Reynolds number at the outgoing end of the furnace will differ from that at the incoming end for the same flow setting. However, in view of the highly turbulent flows in this region, this discrepancy is unlikely to make any detectable difference to flow pattern.

The effect of cold-air infiltration has been studied by arranging inflow of water through the three furnace doors on the model while keeping normal flows through the gas and air ports. This is discussed later in the paper, but it may be stated here that with an air inleakage probably equivalent to more than that

normally encountered in practice, no fundamental alteration was observed in the flow pattern.

Discrepancies due to the neglect of such factors as combustion cannot readily be evaluated by calculation, and further work is now in progress to determine how far the model results are directly applicable. In this work, which is still at an early stage, attempts are being made to map the flow patterns in open-hearth furnaces under steelmaking conditions. A direct comparison between flow patterns in the model and at full scale will then be available, from which it is hoped to check conclusions drawn on the basis of the model results.

It is seen that the simplifying assumptions implicit in the study of flow using the models are unlikely to necessitate serious correction factors at either the incoming or the outgoing ends of the furnace, but they may become important or even predominant in the central portion. Fortunately, from the aspect of design, the two ends of a furnace appear to be more significant and important than the central portion, and a satisfactory approach to similarity seems therefore to have been achieved.

PRESENTATION OF RESULTS

Two principal designs of furnace, the Maerz and the semi-Venturi, have so far been studied. The Maerz model has been modified in two ways : (1) The two air uptakes at either end have been moved inwards so that the inner wall of each lies directly below the sides of the gas port, and (2) the two uptakes have been replaced by a single uptake following the design of *L* furnace at Messrs. Steel, Peech and Tozer (*see* Fig. 45). The semi-Venturi model has also been studied with the monkey walls and air slopes removed.

Flow surveys have been made on each of these five designs, using the procedure already described in Part II. The main operational variables were set as follows.

In all cases rates of water flow were employed such that the gas flows in the model were equivalent to the typical rates of flow in each of the full-scale furnaces during the previous trials[1] at Steel, Peech and Tozer. With the Maerz design the air/gas ratio was approximately equal to the mean air/gas ratio employed on *K* furnace during these trials. With the semi-Venturi model the same air/gas ratio was employed as with the Maerz model merely to simplify comparisons, although in the Templeborough trials a somewhat higher ratio was used. The following figures are the mean flows employed in full-scale trials, and the corresponding routine model flows :

Furnace Type	Gas Flow, cu.ft./hr.	Air Flow, cu.ft./hr.	Air/Gas Ratio
Full-Scale Furnaces*			
Maerz (*K*)	247,000	313,000	1·27 : 1
Semi-Venturi (*S*)	357,000	542,000	1·52 : 1
Model Furnaces			
Maerz	250,000	325,000	1·3 : 1
Semi-Venturi	350,000	455,000	1·3 : 1

* Extracted from Table LXXIII of *Special Report No.* 37, mean figures for trials *K*1, *K*2, *K*3, and *S*1, *S*2, and *S*3, being used.

The higher air/gas ratio employed in the semi-Venturi is of no significance as regards flow pattern, experiments carried out on the model demonstrating that the general pattern was not appreciably affected by varying the air/gas ratio through the entire range of practical values, *viz.*, 1 : 1 to 1·6 : 1. Extreme variations, such as almost completely cutting-off either gas or air, have, of course, a major effect.

An early investigation was made of the effect of altering the partition of waste-gas flow to the air- and gas-checker systems. Again within the entire range of partition ratios found in practice, say, from 60 : 40 to 80 : 20, little significant effect on flow pattern through the model was found.

In order to reduce the number of experiments, the pattern on each design was investigated with a standard air/gas ratio of 1·3 : 1, and the waste-gas partition at 75 : 25. Thus one survey was normally sufficient to establish the pattern with any design. Special investigations were made with other air/gas ratios when the circumstances suggested that they would be of interest.

In the following sections a description is given of the characteristic flow features observed in each of the five designs of model. The flow patterns are illustrated in Figs. 47, 48, and 49. Figure 49 consists of flow photographs together with an explanatory flow sketch. In Figs. 47 and 48 the flow sketches only are reproduced.*

As demonstrated in Part I, a jet entering an enclosed space characteristically sets up entrainment along its length, partly by viscous friction, and this leads to recirculation. Such a jet tends to proceed as far as possible unchanged in direction until deflected by the enclosing walls. The principal features of the flow through the model furnaces can be largely explained with these two principles in mind.

MAERZ DESIGN

Figures 47*a* to 47*c* show the flow pattern in horizontal sections at roof level, gas-port level, and bath level, respectively. Figures 47*d* and 47*e* show the pattern at vertical sections along the furnace centre-line and front wall, respectively. In studying these flow patterns the three-dimensional nature of the flow should not be forgotten ; the patterns are not confined to the plane of the section shown.

Incoming End

The flow pattern at the incoming end is characterized mainly by the presence of the relatively fast gas jet, whilst the preheated air enters the furnace as slower jets through each of the two air uptakes. The gas stream enters the furnace with the normal angle of divergence (about 8°) of a jet, until its underside comes in contact with the slag surface, after which it spreads across the width of the hearth. The incoming

* Considerable difficulties attend the photography and reproduction of these composite photographs and much is inevitably lost of the dynamic character of the patterns which is made apparent, under observation in the models, by the motion of the flow. Unless one is used to looking at these photographs it is not easy to recognize flow features and, therefore, it was decided to include diagrams indicating as simply as possible the principal directions and paths of flow. The photographs from which the diagrams shown in Figs. 47 and 48 were taken are available for inspection upon application to the authors.

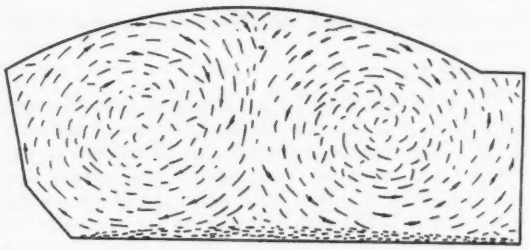
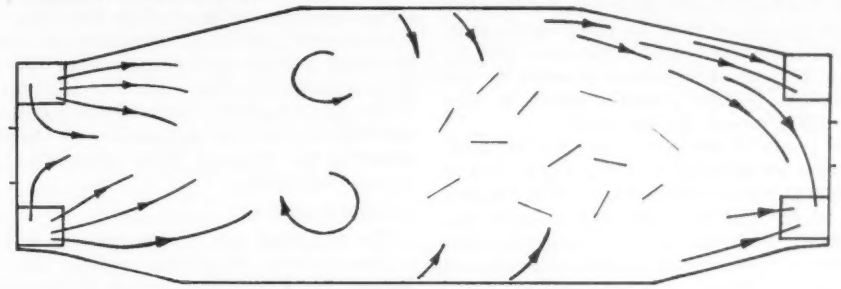
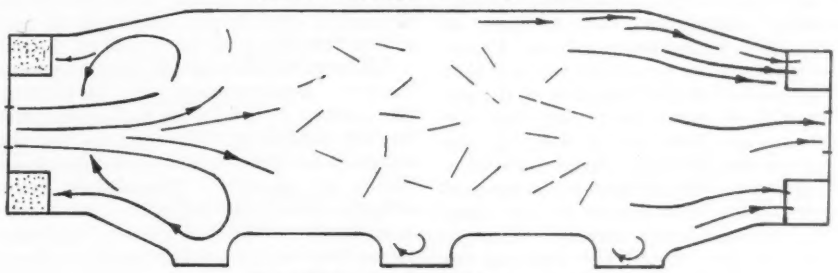


Fig. 46—Vortex flow seen in vertical cross-section at centre of Maerz model

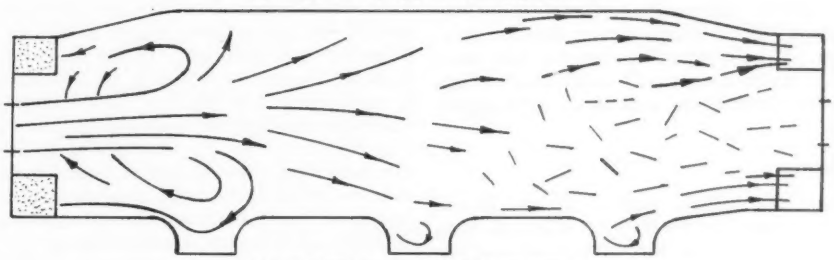
air streams continue upwards after leaving the uptakes until they are turned by the roof; thereafter they fan-out horizontally towards the furnace centre-line and towards the middle of the furnace. Two large stationary vortices exist, one on either side of the gas stream. These vortices are three-dimensional in character and could each be described as having two component axes perpendicular to the gas stream, one vertical and one horizontal. A mixture of air from roof level and of portions of gas discarded by the gas stream is, as a result, recirculated towards the incoming end of the furnace. The recirculated flow



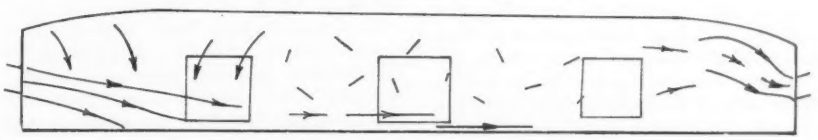
(*a*) Roof level; oxygen bubbles in gas stream



(*b*) Gas-port level; oxygen bubbles in gas stream



(*c*) Bath level; oxygen bubbles in gas stream



(*d*) Centre-line elevation; aluminium powder in air and gas

(*e*) Front-wall elevation; aluminium powder in air and gas

Fig. 47—Flow pattern in Maerz model. Equivalent flows: Air 325,000 cu. ft./hr., gas 250,000 cu. ft./hr. Waste-gas partition 75 : 25

continues back to the gas and air ports where it is observed to flow normally into the issuing streams of gas and air, thus providing entrainment.

Hence, if combustion of the gas stream were taking place, it would be initiated by entrainment of air which has spread along the roof, has been drawn downwards, and has then recirculated back towards the gas port. In so doing, it has been mixed with some of the combustion products. Entrainment in the incoming air jets is met entirely by part of the recirculated flow of these two vortices.

The vortex on the charge side of the furnace extends across the full width of the first door and is somewhat larger than the pit-side vortex, an effect which may be accentuated by the presence of the door and by the greater air flow which is known to enter by the charge-side uptake. The pit-side vortex is also situated somewhat nearer the gas port.

Combustion products, as well as air, are fed back both into the gas jet adjacent to the gas port and to the incoming air as it leaves the uptakes. If the vortex entrainment to the gas jet contained a large proportion of burnt products the rate of combustion would be appreciably slower. A quantitative estimate of the effect has not been made, but qualitatively, if tracer bubbles are placed in the gas stream only, any tracer recirculating round the vortices may be considered to represent combustion products. Figure 47*c*,* having no tracer in the air supply, showed that an appreciable amount of the entrainment to the gas stream does consist of burnt gas; also that the proportion of burnt gas entrained directly by the incoming air is much less, although clearly detectable.

A cross-section immediately in front of the gas port shows that virtually no entrainment of the rising air into the gas stream occurs directly. The gas enters the furnace in the forward direction and the air enters in an upward direction, and initially both flows appear entirely independent of each other, so that little, if any, air is drawn across directly into the gas stream. This is of interest since it has been claimed for the Maerz design that maximum mixing is ensured by the entry of fuel and air at right-angles to each other.

Central Portion

Flow through the central portion of the Maerz model is characterized by turbulence which is considerable and fairly uniform throughout, so that no distinctive pattern is generally apparent. As a result, flow along the back and front walls, including the adjacent parts of the roof, is at least as fast as that through the centre of the furnace. Just above the bath, however, a faster-moving layer of the incoming gas stream persists, and in vertical sections along the back and front walls this is seen to be rising with a gradual slant towards the roof.

Viewing a vertical cross-section at the centre of the model (Fig. 46) a distinctive pattern is seen—two vortices side-by-side in the vertical plane with their axis along the length of the furnace. These two vortices cover almost the entire furnace section, the flow having components upwards at the back and front walls, inwards along the roof, and downwards at the centre of the furnace.

Outgoing End

The outgoing end of the furnace is characterized by a line-up of the flow in the direction of the exit ports. This feature is common to all designs so far studied but, even so, each design has certain distinctive features. Most striking in the Maerz model is the way in which the fastest flows are concentrated at the pit side of the furnace, mainly along the back wall and under the nearby parts of the roof. Moderately fast flows also occur near the front wall, while along the furnace centre-line the flow is slowest. Considerable instability of pattern is observed, and for short periods at irregular intervals the fastest flows occur on the front wall. This inherent instability of flow pattern affects the waste-gas partition between the outgoing air and gas ports, and the manometers metering the outgoing flows indicate a state of continual fluctuation.

General Features

The incoming gas stream appears to be deflected a few degrees off-centre towards the back wall. Indeed, the whole flow through the furnace is asymmetrical. The asymmetry in the gas jet may possibly account at least in part for the great preponderance of fast flow along the back wall at the outgoing end.

Although the flow at the incoming end is shown in the respective manometers to be extremely steady, the pattern in the latter half of the furnace shows marked instability. This suggests that the structural design of the furnace is such that stable flow throughout is not possible. Immediately under the roof, irregular slowly moving eddies are found, but there is no large recirculating vortex; in other words, the mean flow at the middle door is everywhere in a forward direction.

As described in Part II, flow surveys have been carried out using tracer in gas alone, air alone, and in air and gas combined. In the incoming half of the furnace, the use of tracer in the gas alone shows in a qualitative way that a considerable amount of waste-gas products are recirculating (*see* Fig. 47*b** and also Fig. 35 of Part II). The presence of tracer in the air alone illustrates the extent to which air penetrates the gas jet in the mixing zone (Fig. 50). It is also apparent how the air acquires momentum and hence velocity, on being entrained in the gas jet. The backward flow due to recirculation is seen to feed both the incoming air and the gas jet.

Experiments have been carried out with varying air/gas ratios. Whilst no appreciable change in pattern was observed over a relatively wide range of ratios, when the ratio is increased indefinitely, the gas being finally cut off altogether, certain alterations to pattern do occur. Removal of the gas jet causes the disappearance of the two large vortices in the horizontal plane, but the vertical vortices at the air ports remain. In the central portion of the furnace, flows are forward throughout; on the outgoing end, although total speeds and degree of instability are both reduced, the pattern still bears considerable resemblance to that for normal working. When the air/gas ratio is indefinitely reduced, so that finally

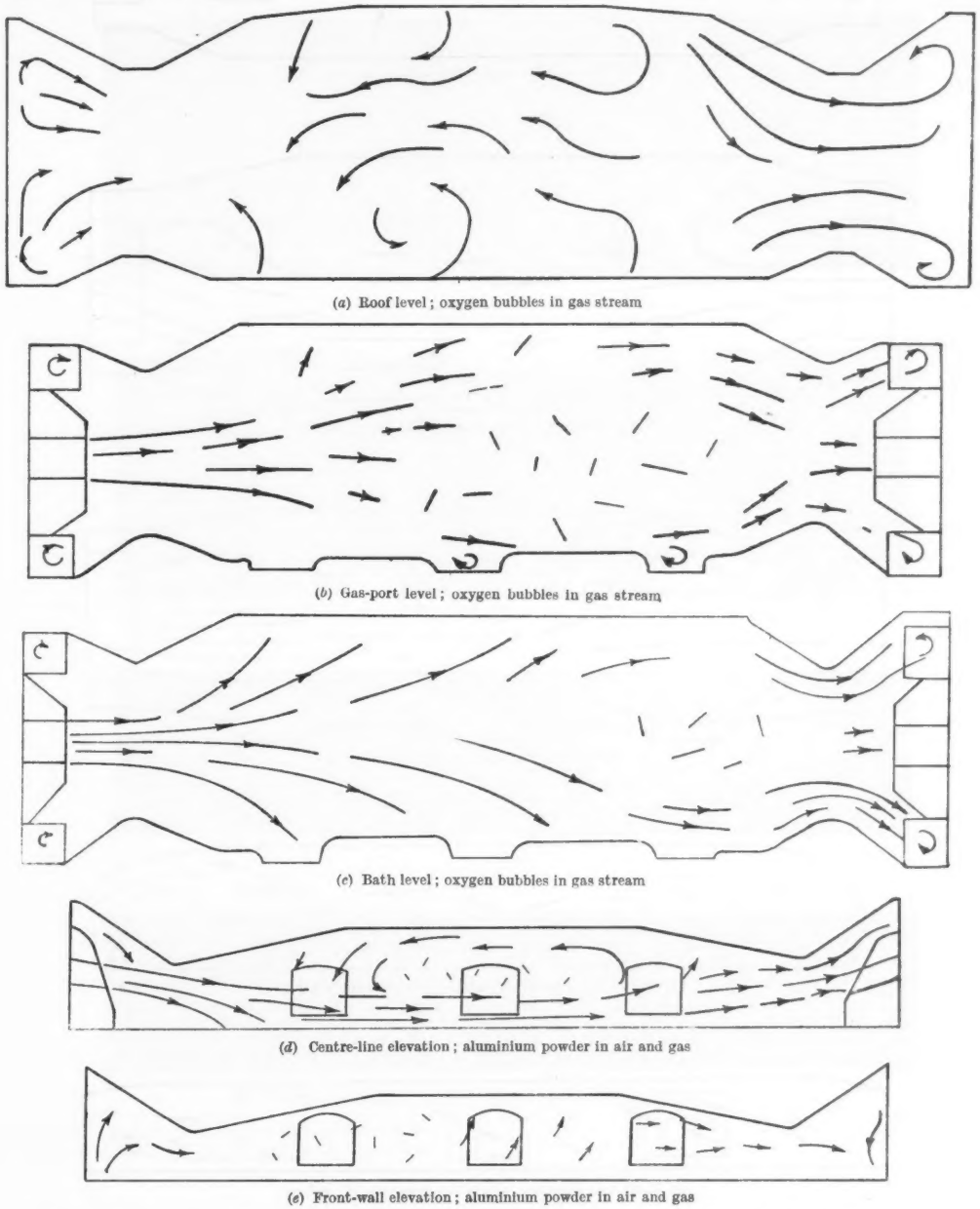
* Refers to original photograph.

the air is cut off altogether, the pattern in the central portion of the furnace changes completely : a fast gas stream passes along the lower levels of the furnace, while the upper levels are filled by a large backward flow in the form of an elongated vortex under the roof. Under these conditions the flow in the central portion of the furnace resembles the flow through the semi-Venturi (described later), rather than through the Maerz, under normal working conditions.

It should be noted for reference that flows in the air uptakes, both incoming and outgoing, show no evidence of spin.

MAERZ MODEL, WITH MODIFIED AIR UPTAKES

It was considered that the high flows at the outgoing end along the back and front walls (particularly along the back wall) in the Maerz, might be caused by the air uptakes being adjacent to these walls. With the



(*a*) Roof level ; oxygen bubbles in gas stream

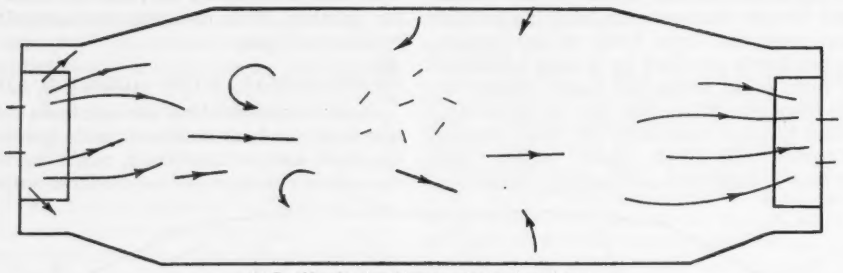
(*b*) Gas-port level ; oxygen bubbles in gas stream

(*c*) Bath level ; oxygen bubbles in gas stream

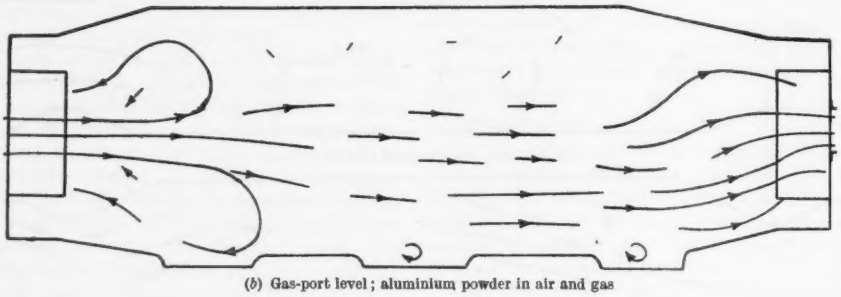
(*d*) Centre-line elevation ; aluminium powder in air and gas

(*e*) Front-wall elevation ; aluminium powder in air and gas

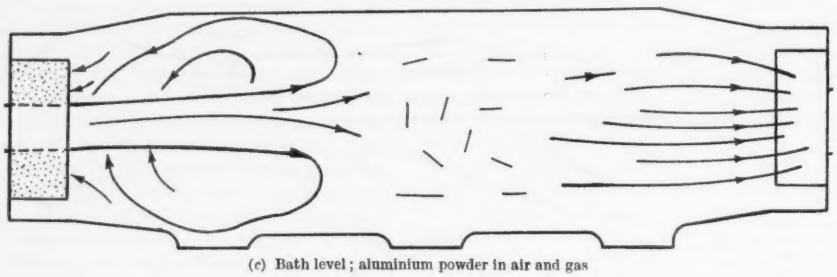
Fig. 48—Flow pattern in semi-Venturi model. Equivalent flows: Air 455,000 cu. ft./hr., gas 350,000 cu. ft./hr. Waste-gas partition 75 : 25



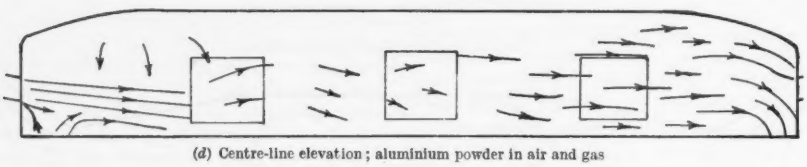
(*a*) Roof level; aluminium powder in air and gas



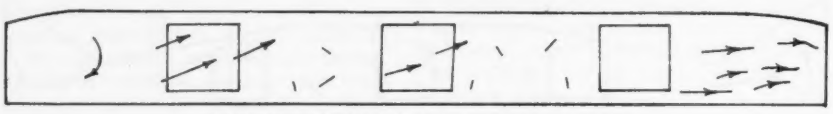
(*b*) Gas-port level; aluminium powder in air and gas



(*c*) Bath level; aluminium powder in air and gas

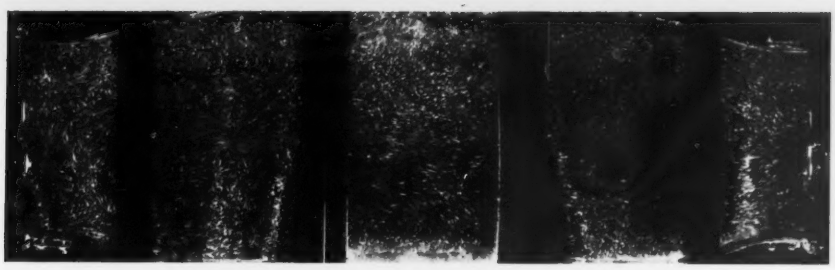


(*d*) Centre-line elevation; aluminium powder in air and gas

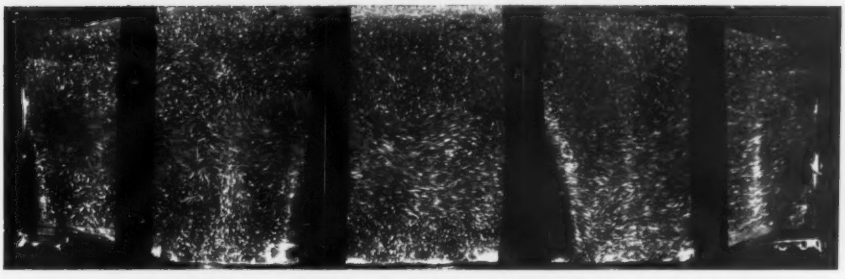


(*e*) Front-wall elevation; aluminium powder in air and gas

Fig. 49—Flow pattern in single air-uptake furnace model. Equivalent flows: Air 325,000 cu. ft./hr.,



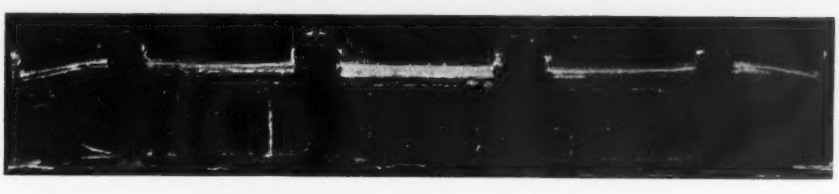
(*a*) Roof level; aluminium powder in air and gas



(*b*) Gas-port level; aluminium powder in air and gas

(*c*) Bath level; aluminium powder in air and gas

(*d*) Centre-line elevation; aluminium powder in air and gas



(*e*) Front-wall elevation; aluminium powder in air and gas

gas 250,000 cu. ft./hr. Waste-gas partition 75 : 25. Exposure time $\frac{1}{130}$ sec., (*a*) to (*c*) front-wall illumination

[*Halliday and Philip*
[*To face p.* 408

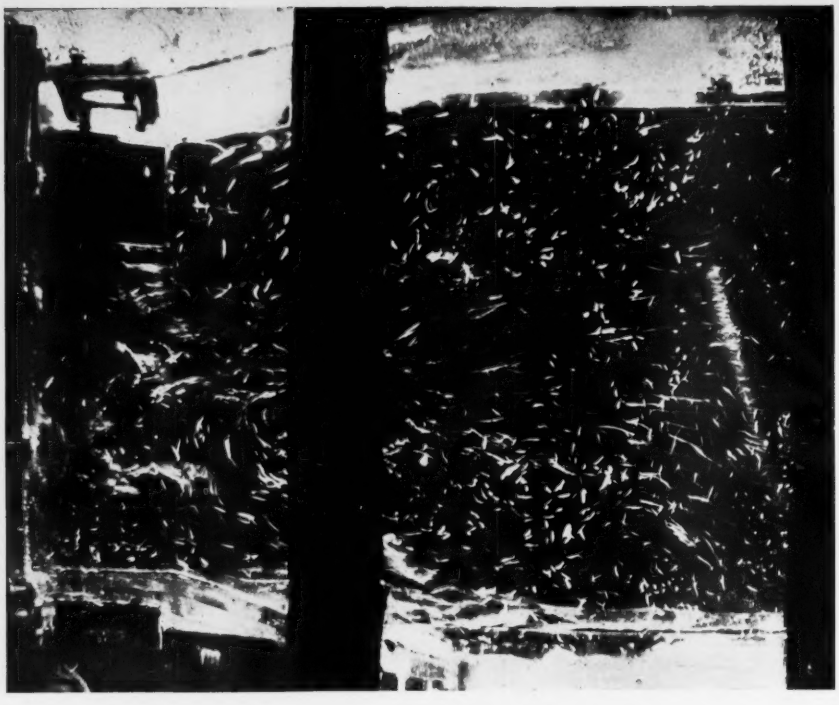


Fig. 50—Pattern shown by oxygen tracer in air flow at incoming end of Maerz model at bath level (no tracer in gas supply)

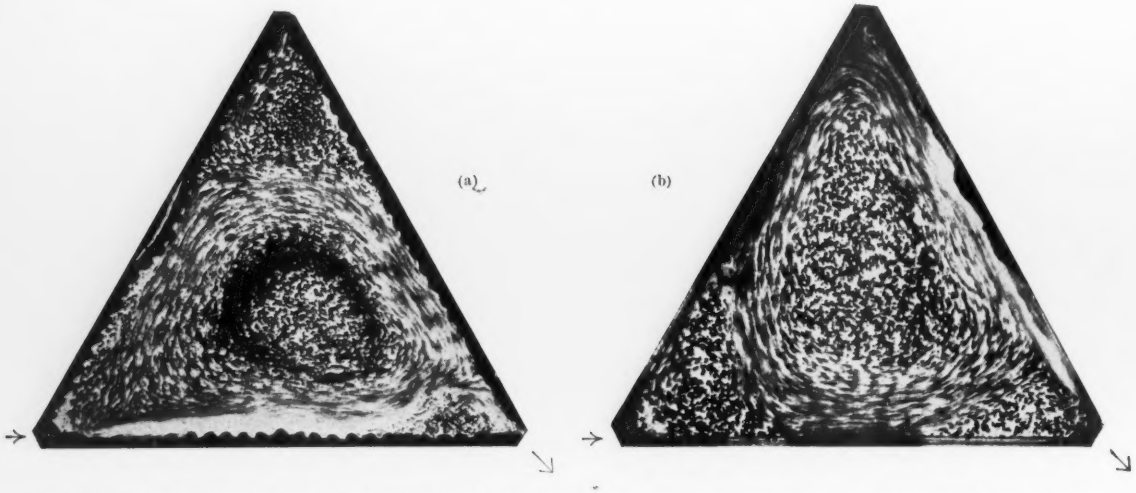
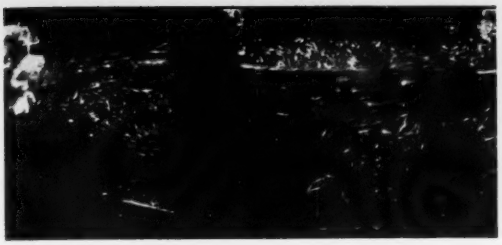
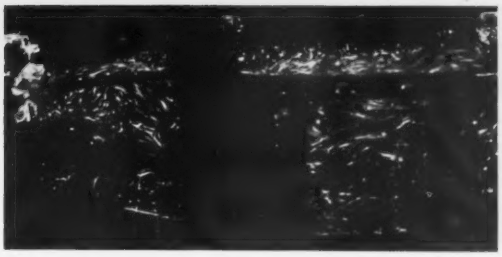


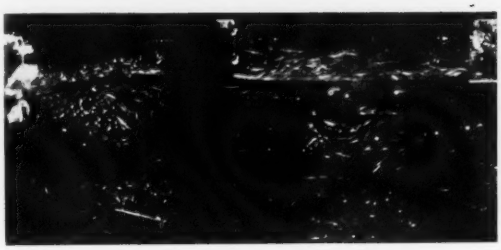
Fig. 51—Flow pattern of jet along one side of shallow triangular tank; (a) with corrugated walls, (b) with smooth walls



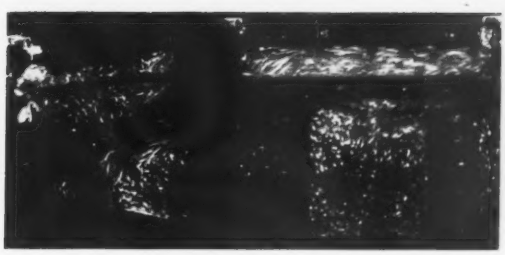
(a) 250,000 cu. ft./hr.



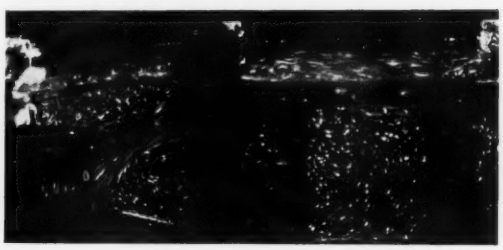
(b) 200,000 cu. ft./hr.



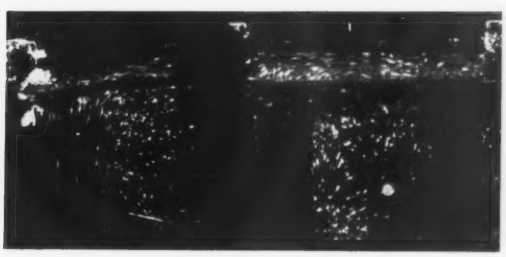
(c) 150,000 cu. ft./hr



(d) 100,000 cu. ft./hr.

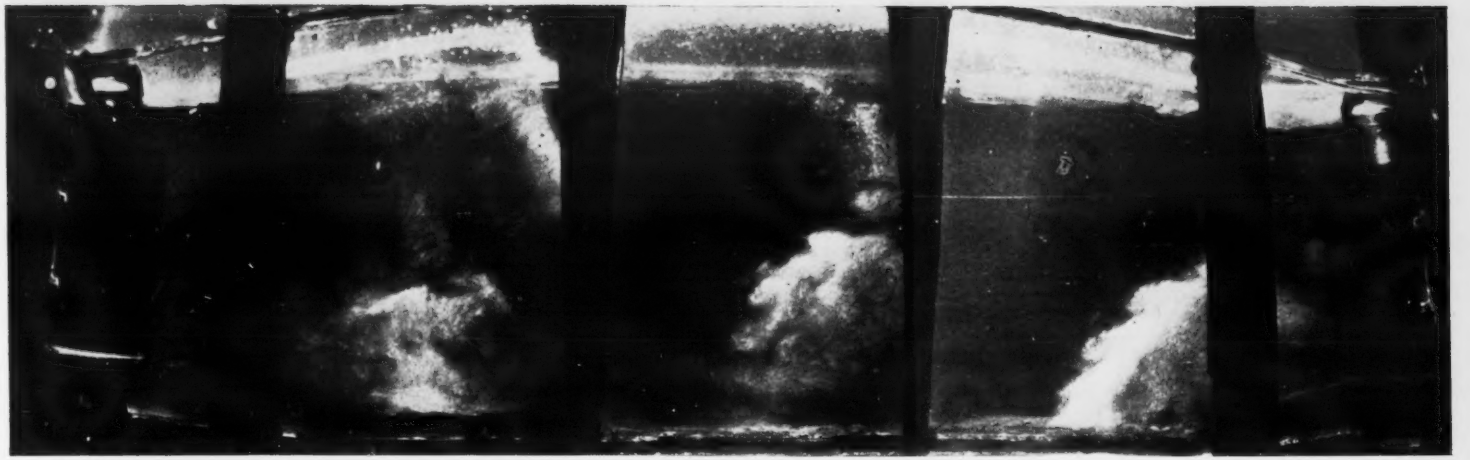


(e) 50,000 cu. ft./hr.

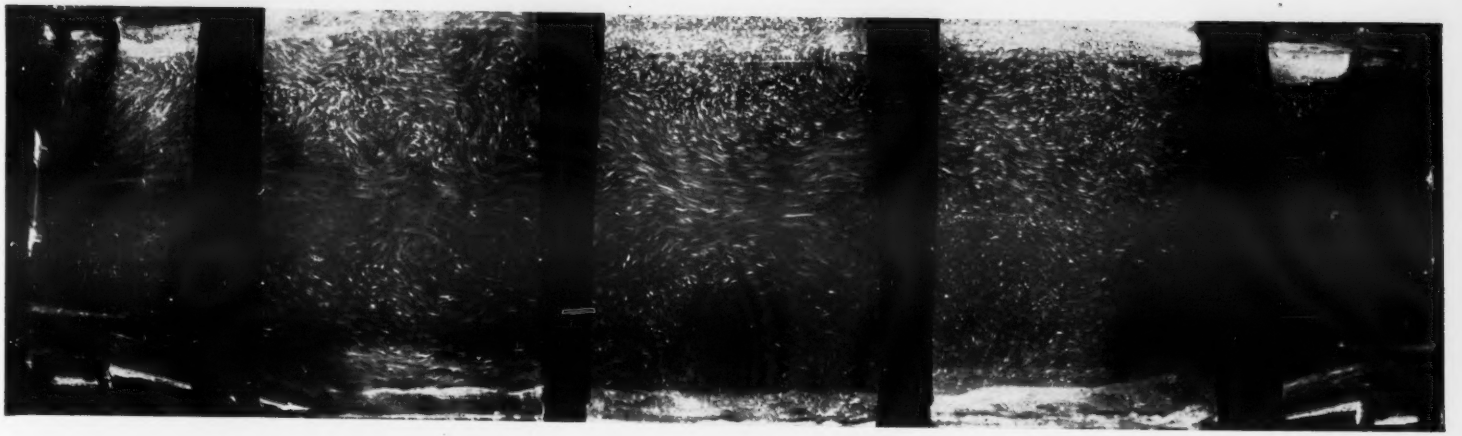


(f) No gas

Fig. 52—Effect of reducing gas flows, but with constant air flow at 325,000 cu. ft. hr., on single uptake model



(a) Tracer in air inleakage



(b) Tracer in normal flow

Fig. 53—Single uptake design working at normal flows with air inleakage

air uptakes nearer to the gas port it might be expected that the faster flow rates would be found nearer the centre of the furnace. At the same time, at the incoming end such an arrangement might allow for more direct mixing of the incoming air with the gas than on a standard design.

However, the pattern of flow at the incoming end was largely as in the normal design, the stationary vortices again being present. Unexpectedly, the gas jet was diverted somewhat towards the front wall, producing the effect in the outgoing portion of the furnace of faster flows near the front wall, with comparatively low flows at the centre and back walls. The front-wall flows on this design were almost as rapid as the back-wall flows in the Maerz. The removal of the outgoing-air uptakes from the furnace walls resulted merely in the outgoing stream swinging in more sharply from wall to uptake. A test made with this design showed that the gas could be safely reduced without also reducing the air, in spite of the close proximity of the air uptakes to the gas port.

SINGLE AIR-UPTAKE DESIGN

The Maerz model was modified to conform as nearly as possible to the single air-uptake design recently installed on *L* furnace at the Rotherham Melting Shop of Steel, Peech and Tozer. Because *L* furnace at the Rotherham Melting Shop and *K* furnace at the Templeborough Melting Shop (the full-scale original of the model) had different overall dimensions and differences in shape, it was not convenient to arrange for exact geometrical similarity between the model and *L* furnace. The principal differences are in general dimensions, *L* furnace being shorter and wider than *K*, and of somewhat smaller capacity (65 tons as compared with 80 tons), and *L* furnace has a ramp roof.

The pattern observed on this design (Fig. 49 *a* to *c*) is in many respects quite different from those of the Maerz and its modification with close uptakes. The most outstanding difference lies at the outgoing end, where the streaming to the exit air and gas ports is largely confined to the central portion of the furnace, with a slight bias towards the front wall. Flow speeds along the front wall, and more particularly along the back wall (12 ft./sec.), are very low when compared with those of the Maerz (24 ft./sec.). These figures are equivalent velocities for full scale. Furthermore, the flow at the outgoing end of the furnace was much more uniform and stable. This stability is confirmed by steady manometer readings of the outgoing flow, indicating that the partition between gas and air exit ports varies little.

At the incoming end the pattern shows no abnormal features. The stationary vortices are present, as with the two previous designs, although they are not so extensive as with the Maerz design. This seems to be due to the fact that part of the entrainment for the gas jet is received directly on the underside and sides of the jet from the air rising through the single uptake. There is also a decrease in apparent length of the gas jet, which merges quickly in the general furnace flow. This effect is probably brought about by the more intimate mixing of gas and air.

In the centre portion of the furnace the degree of turbulence appears to be less than in the normal Maerz design, possibly owing to the lower air speeds in the air uptake, which has a greater area than the two normal uptakes combined. Fast flows in this region also tend to be confined to the centre of the furnace, with very low speeds along the back wall.

Investigation of the effect of variation in the air/gas ratio on this design shows up a feature absent in standard furnaces, *viz.*, that for maintenance of flame inclination the air/gas ratio must be limited. If the gas flow is cut, without a simultaneous cut in air flow, the gas jet becomes diverted towards the roof (Fig. 52). Measurements of the lift of the gas jet in the single air-uptake model, made on these model photographs, for various air/gas ratios, are as follows :

Air Flow, cu.ft./hr.	Gas Flow, cu.ft./hr.	Air/Gas Ratio	Angle of Lift of Gas Jet
325,000	250,000	1·3 : 1	2½°
325,000	200,000	1·6 : 1	11°
325,000	150,000	2·2 : 1	17½°
325,000	100,000	3·2 : 1	43°
325,000	50,000	6·5 : 1	55½°

The angle of inclination of the gas port downwards from the horizontal is 10½°, and in the normal Maerz-design model the gas jet follows this angle closely. With the single-uptake design, however, the jet is lifted 2½° at flows equivalent to normal full-scale working. With an air/gas ratio of about 1·6 : 1, the jet is inclined slightly above horizontal, while further reducing the gas causes the jet to lift more severely. This feature is known to occur on the full-scale furnace, although quantitative measurements have not been made over the range of flows covered by the model owing to risk of damage to the roof. It has been estimated, however, that on *L* furnace (gas port inclined 10°) a lift of up to 5° occurs under normal working conditions.

A comparison with Fig. 22 of Part I suggests that such critical effects may be expected when jets impinge at right-angles.

SEMI-VENTURI DESIGN

The flow pattern of the semi-Venturi design is shown in Fig. 48.

Incoming End

As in the Maerz design, under normal flow conditions, the incoming gas stream enters the furnace in the form of a jet with a fairly normal angle of divergence, until it comes in contact with the bath surface ; it then fans out across the width of the bath.

The incoming air behaves in quite a distinct manner. The air entering through each uptake has a marked spin, clockwise when viewed from above. This direction refers to a gas flow from left to right when viewed through the doors. (With the gas from right to left the spin would doubtless be counter-clockwise.) A proportion of the air rises directly to the ramp roof and is guided round into a forward and downward direction between the port block and the ramp roof, so as to feed on to the gas stream mainly from above. The remainder of the air does not rise to the ramp roof, but on reaching the top of the uptakes it follows a more gradual turn and passes down between the gas-port block and monkey walls. In this way air is drawn mainly on to the sides of the gas jet.

There is, of course, no distinct boundary between these two portions of the air flow.

Apart from small vortices at the side of the air uptakes, there is a notable absence of vorticity in this region below the ramp roof. Direct entrainment of the incoming air in the gas jet is apparently ensured by the constraints imposed by the Venturi throat and particularly the sloping ramp and the port block. Thus the general appearance of flow through the semi-Venturi, as far as the knuckle section, is that of forward-flowing streams of air converging on the gas stream. The spin observed in the uptakes does not extend as far as the gas port.

Central Portion

The flow in the portion of the furnace between the knuckles is very different in character from that observed with the Maerz design. A vertical section on the port-to-port centre-line shows the presence of a large elongated vortex with horizontal axes. The lower part of this vortex consists of the main furnace flow and the upper part a return flow under the roof.

The fast gas stream under the knuckle at the incoming end continues the length of the bath. Thus the lower furnace regions contain fast-moving streams of gas, air, and combustion products. Above an abrupt upper limit to this type of flow in the furnace there is a region of indeterminate flow with unstable pattern, and higher still, under the arch of the roof, there is a pronounced and fairly rapid backward or return flow. On *S* furnace, at the middle door, the height from slag level to the crown centre is 7 ft. 3 in. The regions observed on the model correspond to forward flow over the bath in a 2 ft. 6 in. zone, indeterminate flow above this for a height of 1 ft. 9 in., and a back flow in a 3-ft. layer under the roof. These figures will be compared later with the results reported in *Special Report No.* 37.

In the Maerz model it will be remembered that a similar pattern was noticed when the air flow was entirely cut off, but was absent with a normal air/gas ratio.

Outgoing End

Conditions at the outgoing end bear a certain similarity to those found in the Maerz, in that there is a general line-up of the flow towards the outgoing ports. Again the fastest flows are along the back and front walls, with lower flows near the centre of the furnace. Much less asymmetry, however, exists as between front and back wall, and the flow pattern at the outgoing end is relatively stable. Waste gases leaving the furnace through each air uptake can be considered to consist of two separate streams. Part of the flow passes directly between the port block and monkey wall, but part ascends over the top of the port block and close to the ramp until it is abruptly turned into the uptakes by the end wall.

On reaching the air uptakes the gases acquire a marked vorticity. At this end of the furnace, however, the direction of spin as viewed from above is clockwise at the charge-side uptake and counter-clockwise at the pit-side uptake, the general flow being from left to right when viewed through a door. The vorticity was more noticeable at the charge-side uptake than at the pit-side uptake.

General Features

As with the Maerz model, variation of the air/gas ratio and of the outgoing partition has (within normal limits) little or no effect on the observed patterns. Additional experiments have been carried out with gas and air reduced to very low values, and with gas or air only. When air is reduced, and even shut off altogether, there is little significant change in pattern, but, with gas sufficiently reduced or cut off altogether, a marked change occurs within the central portion of the furnace. The large vertical vortex disappears and forward flow takes place throughout the entire model between the knuckles.

SEMI-VENTURI MODEL, WITH MONKEY WALLS AND AIR SLOPES REMOVED

The standard design of semi-Venturi furnace was modified by removal of the monkey walls and the air slopes. The outstanding feature of this modification was the unexpected similarity of pattern to that of the standard design. It was thought that removal of the monkey walls especially might lead to the setting up of vortices at the incoming end, similar to those observed in the Maerz furnace, and also to recirculation around such vortices. No such phenomena were noticed. The space previously occupied by the monkey walls appeared to consist largely of 'dead space,' and virtually no gas recirculated back under the knuckle. The flow distribution in the central and outgoing portions of the model also showed little change from that of the original model.

These results suggest that the characteristic pattern of the Venturi is brought about mainly by the contraction in area at the knuckle due to the ramp, and that the presence of monkey walls is relatively unimportant in this connection.

FEATURES COMMON TO ALL MODELS

Door Vortices

Vortices in each door space were noticeable in all the furnace models. These vortices had vertical axes, and although they could be observed revolving horizontally, they were difficult to photograph. At the incoming door the vortex in the Maerz model was combined with the large recirculating vortex associated with the gas jet on the charge side. At the middle and outgoing doors the vortices were usually quite small and were confined to the space between the door jambs. In other words the main flow along the front wall tends to ignore the presence of the doors, but results in induced recirculation in the space between the jambs. The vortices observed at the doors, when sealed, disappear when large air inleakage takes place.

Effect of Piled Scrap

Although the main study of flow pattern in the various designs has been confined to the case of a flat-melted bath 6 in. below sill-plate level, clearly no design could be considered satisfactory if the flow pattern were adversely affected by piled scrap. Whilst allowance should be made for the different shapes and positions of cold scrap charged in practice, an initial survey has been carried out on the Maerz furnace by placing rectangular blocks in front of one

or more of the three doors. These blocks correspond roughly to charged ingot moulds. The flow pattern under these conditions showed (Fig. 54) considerable alterations up to the level of the top of the blocks, but above this the effect was very small. This result, however, might not apply with other types of scrap.

Surface Roughness

Throughout this work no account has been taken of the effect of surface roughness. Complete geometrical similarity would require the interior roughness of the perspex model to be scaled down exactly from the brick-face roughness of the full-scale furnaces. This, in itself, would be extremely difficult to ensure owing to lack of an adequate measure of surface roughness both on the model and at full scale. In practice the effect of roughness would be most noticeable in its result on pressure distribution. For example, the degree of roughness of the gas-port walls may allow more or less gas to enter a furnace for the same pressure drop.

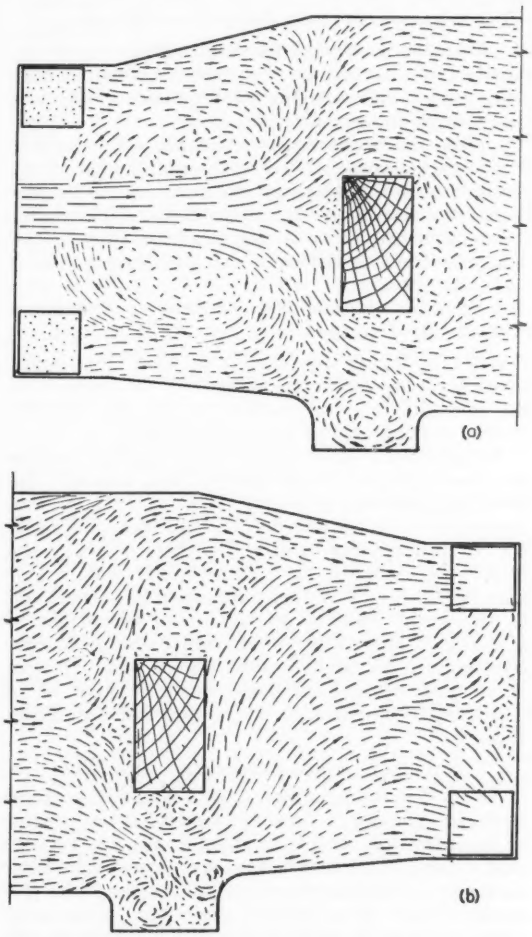


Fig. 54—Sketches of flow at bath level, past rectangular blocks placed at (*a*) incoming and (*b*) outgoing ends of Maerz model. Flow conditions otherwise normal

It is most unlikely, however, that neglect of similarity in surface roughness will make any detectable difference in the flow pattern. This is strikingly borne out by two-dimensional tray experiments as described in Part I. Thus, if deep corrugations are fitted along the walls of a triangular tank, the flow pattern (Fig. 51*a*) is not appreciably different from that with smooth walls (Fig. 51*b*) ; nor with the jet set at other positions were the patterns significantly affected by the corrugations. This conclusion may be compared with the work of Williamson,[62] who considers that " counterflow and circulation " in a confined channel is associated with vortices generated from the rough surfaces of the bottom and sides of the channel.

Velocity Measurements

Measurements have been made of the velocities of tracer bubbles in the models. The technique employed has been detailed in Part II, together with the precautions necessary in considering these determinations. In this way, downstream components of velocity in the three models have been plotted on grid diagrams, of which Fig. 40 in Part II is an example, and transverse components have been computed.

Owing to the corrections required, a detailed analysis of the velocities is not here attempted. The following, however, are typical figures of downstream velocity components, for various portions of the three designs at gas-port level, and at the roof, gas-port, and bath levels on the semi-Venturi model :

Downstream Equivalent Velocity Components (feet per second) at Gas-Port Level on Three Model Designs

	Incoming End	Middle Door	Outgoing End
Semi-Venturi			
Back wall	10	10	30
Centre-line	75	30*	25
Front wall	15	30	35
Maerz			
Back wall	−15	20	30
Centre-line	65	Variable −15 to +10	15
Front wall	−10	Variable −15 to +10	20
Single Uptake			
Back wall	−10	10	15
Centre-line	75	25	35
Front wall	−20	25	25

Downstream Equivalent Velocity Components (feet per second) at Three Levels on the Semi-Venturi Model

	Incoming End	Middle Door	Outgoing End
Roof Level			
Back wall	−5	−15	25
Centre-line	Variable −10 to +10	−15	15
Front wall	10	−15	30
Gas-Port Level			
Back wall	10	10	30
Centre-line	75	30*	25
Front wall	15	30	35
Bath Level			
Back wall	Variable −5 to +10	35	30
Centre-line	100	40	25
Front wall	35	35	35

* At a slightly higher level, negative velocity components are noted at this position which is near the top of the forward-flowing stream.

The velocities have in all cases been converted, as described in Part II, to "equivalent velocities at full scale." This conversion takes no account of the effect of combustion, but a steady rise of temperature across the bath from 1350° C. at the incoming end to 1650° C. at the outgoing end has been assumed. The foregoing velocity values, however, provide a basis for comparing typical downstream velocities of flow in various regions of the models. Transverse velocities are not here discussed.

The downstream velocities on the three model designs give a numerical interpretation to many of the flow features already described. For example, at the incoming end, negative velocities near the front and back walls on the Maerz and single-uptake designs are due to the recirculating vortices. The instability of flow in the central portion of the Maerz model can be noted, and a comparison can be made of the distribution of velocity at the outgoing ends of the three models.

In the three sets of velocities for the semi-Venturi design, the main flow features previously described are apparent. In particular, the back flow under the roof and the fast flows over the bath in the central portion of the furnace can be noted. It appears, too, that the downstream velocity distribution at the outgoing end on this model is roughly the same at all three levels.

AIR INLEAKAGE

Experimental Procedure

The effect of air inleakage has been studied by injecting water through 1-in. dia. pipes inserted, with water-tight seals, through holes in each door of the single air-uptake model. Each hole was cut as low in the door as practicable, in order that inleakage should enter the model at positions corresponding to the regions of lowest pressure on the full scale. Large-diameter holes minimized the jet action of the injected flows. Conditions therefore correspond to the case of doors approximately one-third open.

The similarity criteria to be applied in the case of cold air inleaking through a furnace door require special consideration. Air, of velocity, density, viscosity, and temperature very different from that of the furnace gases, enters and rapidly proceeds to mix with and rise to the temperature of the general furnace gases. Furthermore, the streaming into the furnace (as shown by the model) is unsteady, so that space near the doors may be occupied one moment by furnace gases and the next moment by inleaking air. The absence of steady conditions and the difficulty of prescribing any characteristic length for the inleaking air makes the specification of Reynolds number of doubtful meaning, if indeed possible. Strict similarity is unattainable since it is not possible to simulate on the model the effect of the difference in density of the cold inleaking air compared with the hot furnace gases. Even were liquid of about six times the density of water available to represent cold air at the moment of entry, no account could be taken of the drop in density of the inleaking air as it heats up by mixing.

The basis adopted as most reliable was to choose 400° C. as the mean effective temperature of the inleaking air on entering the furnace. If this temperature were too high, the inleakage on the model would correspond to even higher rates at full scale.

Figure 53 shows two plan views at the level of door centres in the single air-uptake model, with air inleakage passing through the three doors equivalent on the above basis to 167% of the metered air. In Fig. 53*a* the inleaking air is visualized by tracer air bubbles. No tracer is present in the normal gas and air supplies, so that the interior of the model appears dark except where there is inleaking air. In Fig. 53*b* tracer has been introduced as usual into the general flow, but not into the inleaking air, so that the flow pattern through the furnace is shown up while the inleaking air appears dark.

Effects of Air Inleakage

While the rate of inleakage is probably greater than that normally existing on furnaces in practice, no great difference is observed with lower and more normal rates of leakage in the courses followed by the inleaking streams.

The behaviour of these streams is as follows :

From the Incoming Door—Inleaking air is absorbed into the recirculating vortex associated with the gas jet, and is largely carried back to form part of the gas-jet entrainment.

From the Centre Door—Inleaking air is carried towards the outgoing end by the main furnace flow, and most of the inleakage stream is confined to the charging side of the furnace, although occasionally a portion breaks away and penetrates across the furnace towards the back wall and the pit side of the air uptake.

From the Outgoing Door—Inleaking air almost wholly flows to the charge side of the air uptake.

With the higher inleakage rates there is an additional tendency at the incoming door for fractions of the inleaking air to penetrate across the furnace instead of being carried back to the gas jet.

No appreciable difference in the general flow pattern has been observed with and without leakage, the inleaking air merely becoming absorbed in the existing flow pattern. At the outgoing end, however, the faster central flow appears to extend slightly nearer to the back wall (compare Fig. 53*b* with Fig. 49*b*). This may be due both to a slight alteration in pattern and to the larger volume flowing under conditions of inleakage. The effect would seem to be of no consequence in the single-uptake design but, although small with normal inleakage rates, it may be of considerable importance in a conventional Maerz furnace.

GENERAL DISCUSSION OF RESULTS

The first striking feature of the model flow patterns is the complexity of flow. In observing the passage of flame through an open-hearth furnace, any vortices and regions of backward flow are normally invisible to the eye, while the luminous part of the flame proceeds always in a forward direction. The model results are not, therefore, necessarily inconsistent with the operation of a production furnace.

Deflection of the gas jet towards the pit side, with consequent high gas velocities along the back wall

near the outgoing end, is interesting as a factor in refractory wear, particularly on the Maerz design. Asymmetry of the visible flame has been observed on full-scale furnaces; indeed, with certain designs the gas port is deliberately inclined at a small angle towards the front wall to counteract the effect. The asymmetry has also been ascribed to the inleakage of cold air through the doors, but model results show that the cause may be inherent in the structural design of the furnace itself. The particular feature resulting in asymmetry is still unproved; it may be asymmetry in the design of the furnace chamber, or unequal flows through the charge and pit-side air uptakes.

In certain designs considerable pattern fluctuations occur towards the outgoing end of the furnace, even with steady input rates. The outgoing flow is then essentially unstable, a feature which might well have been predicted from the experiments on two-dimensional tanks (Part I). This instability is probably the main reason for the observed fluctuations in waste-gas analyses at the uptakes of full-scale furnaces.

When a fluid flows through a straight pipe the fastest flows are near the centre, while close to the wall there is a rapid decrease in velocity. Along the length of an open-hearth furnace a somewhat similar state of affairs might have been expected, particularly in view of the presence of the fast gas jet along the centre of the incoming end. Both the Maerz and the semi-Venturi designs, however, show peculiar exit-velocity distribution; the fastest flows occur near the walls, and flows near the centre are relatively slow and unstable. The cause was thought to be the location of the downtakes close to the back and front walls of the furnace, but the modified Maerz design, with closer uptakes, gave no great improvement. In the single air-uptake design, however, the fast flows are notably confined to the centre of the furnace.

On a full-scale furnace the gases at the outgoing end will carry a considerable oxide pick-up from the bath and, as discussed later, the fast wall flows at this end may, therefore, be an important factor in roof and back-wall wear.

The glancing flow of the fast-moving gas stream on to the bath, and the consequent splaying-out effect, is probably mainly responsible for the twin vortices observed in the cross-section through the centre of the Maerz model (Fig. 46). The momentum of the gas jet in the semi-Venturi model is apparently also responsible for the back flow under the roof. This is confirmed when gas is cut off completely in this model, a forward flow being established under the roof. A similar conclusion is arrived at on the Maerz model when reducing the air sufficiently results in a strong back flow under the roof.

Certain comparatively large design alterations to the model have only a small effect on flow pattern. The most notable example of this so far is the removal of monkey walls and air-port slopes on the semi-Venturi furnace already discussed. On the other hand, certain comparatively small alterations to design critically affect the flow, and it is therefore important to discover which features are significant and which are not, in their effect on flow.

RELATION OF FLOW PATTERNS TO FULL-SCALE DATA

In spite of the neglect of combustion effects in the model work, certain comparisons can be made between the flow features observed on the Maerz and semi-Venturi models and the results obtained on the full-scale furnaces (*S* and *K*, at Templeborough) during previous trials.[1] Indeed, it was partly to facilitate such comparisons that the first two models constructed were of *K* and *S* furnaces. It is sufficient to limit this comparison to three aspects, *viz.*, furnace gas analyses, cinematograph films of furnace flames, and refractory wear.

Furnace Gas Analyses

The use of a multiple sampling probe for gas analyses has been previously described[1] (*loc. cit.*, Section II, Part 13). Whilst on *S* furnace the probe was inserted only at one position, through the centre of the roof, on *K* furnace the probe was used through three holes in the roof—opposite the middle of each charging door. The agreement between multiple sampling probe results and the observed flow patterns, recorded factually below, may be largely accidental.

The *K* furnace results seem to be in qualitative agreement with the picture built up from study of the model flow pattern. At the incoming door (*see* Fig. 105[1]), the lowest position of the sampling probe shows a high CO_2 reading (10–11%) and a CO content of 7%, and corresponds to the position of the gas jet in the model. All higher positions of the sampling probe gave very low CO_2 values (0·45–3·6%), with high oxygen percentages (17–19%). These correspond to the region in the model in which air is feeding down from the roof on to the jet. The fact that a small proportion of CO_2 was found in all these sampling probe readings could be explained, with reference to the model, as due to the presence of combustion products which have recirculated into the incoming air stream as it leaves the uptakes.

Opposite the centre door the lowest sampling probe position gave a relatively high CO_2 percentage (11–12%) and a low oxygen percentage (5–6%). This corresponds to the shallow fast-moving layer of gas stream seen over the bath of the model. Above this layer the comparative uniformity of CO_2 percentages (7·5–9% mainly) and of oxygen readings corresponds to the region of apparently homogeneous turbulence and mixing observed in this portion of the model.

At the outgoing door almost all the sampling probe readings gave CO_2 and oxygen percentages which, with the excess air employed, indicate that combustion is virtually complete and, as seen in the model, that fully mixed gases are leaving the furnace.

The absence of figures for the incoming and outgoing doors of *S* furnace unfortunately prevents such a detailed comparison. At the middle door, however, the height of the fast-moving forward flow in the model is equivalent to about 2½ ft., while the backward flow under the roof extends to a depth equivalent to about 3 ft. Comparison with Fig. 107[1] shows that the forward-moving stream coincides almost exactly in height with the region in which high CO_2 figures (9·5–11·5%) and low oxygen figures (7–8%) were found with the sampling probe. Also, the back flow

under the roof occupies almost exactly the levels in which low CO_2 readings (approximately 8%) and high oxygen readings (11–12%) were found The intermediate region, about 2 ft. in height, where in Fig. 107[1] the CO_2 and oxygen curves cross, corresponds to the indeterminate zone in the model near the centre of the large vortex.

Cinematograph Films of Furnace Flames

Comparisons are possible between some aspects of model flow and the determinations of flame height and velocity by flame cinematography through furnace doors[1] (*loc. cit.*, Section II, Part 14).

Flame Height—A comparison of Figs. 110[1] and 111[1] with the flow pattern seen in vertical sections on the port-to-port centre-line of the Maerz and Venturi models, Figs. 47*d* and 48*d*, gives some indication of the different condition in the two designs. The films show that in the Maerz design the flame has a high mean level and a marked tendency to rise at the middle door, while on the semi-Venturi furnace the flame is confined more closely to the lower levels of the furnace.

These observations should be compared with the flow in the semi-Venturi model confined to the lower levels of the chamber and with the apparently almost homogeneous turbulence seen in the central portion of the Maerz model.

Flame Velocities—Only in the incoming gas stream of the semi-Venturi furnace was a direct measurement made of gas velocity by filming colour patches in the flame. The figures obtained by this means, together with the gas flow at the time of photography, and also velocities measured on the model with the corresponding equivalent gas flow, are given below :

	Full-Scale Furnace (Actual Values)	Model Furnace (Equivalent Values)
Range of velocities, ft./sec.	56–90	65–119
Mean velocity, ft./sec.	74	86
Gas flow, cu. ft./hr.	320,000	350,000

Mean equivalent model velocity estimated for equivalent gas flow of 320,000 cu. ft./hr.

$$= \frac{86 \times 320{,}000}{350 \quad .000} = 79 \text{ ft./sec.}$$

As detailed in Part II, considerable precautions must be taken in connection with velocity measurements on the model, but it is seen that there is reasonable agreement between the figures of model and prototype.

The following comparison of equivalent velocities along the furnace on *K* and *S* models shows that flow in the semi-Venturi model is considerably faster than in the Maerz, in the lowest levels of the chamber :

Full-Scale Furnaces		Models	
Flame Surge Velocities at Middle Door, ft./sec.	Gas Flow, cu.ft./hr.	Equiv. Forward Velocities at Middle Door, ft./sec.	Equiv. Gas Flow, cu.ft./hr.
Maerz			
16	248,000	10	250,000
Semi-Venturi			
36	367,000	30	350,000

These figures may be compared with the surge velocities measured on the films of *K* and *S* furnaces (extracted from Table LXVI of *Special Report No.* 37). It should be noted, however, that surge velocities are not necessarily directly related to flame speeds.

Refractory Wear

Considerable evidence exists that wear on furnace roofs and back walls may be due to an important extent to erosion caused by high-velocity flow, in particular at the outgoing end of the furnace, where combustion products carry in suspension particles of iron oxide, lime, etc. Wear would therefore be aggravated by the fast exit flows on both the Maerz and the semi-Venturi, which in the models were observed to be concentrated near the back wall and front wall and adjacent parts of the roof.

Comparison of flow through a model with the wear on the full-scale furnace from this angle is complicated. The two-directional flow due to reversing of the large furnace masks the pattern of wear resulting from fast-moving particle-laden gases in one direction. It is therefore necessary to consider the model also as if it were working on a reversing principle and to superimpose the flow pattern with the gas in one direction upon the flow pattern with the gas reversed.

Zea has illustrated[1] (*loc. cit.*, Figs. 65 and 66) the roof wear on *K* and *S* furnaces during campaigns which included the trials at Steel, Peech and Tozer. It can be noted that flows tend to be fast in regions where wear is pronounced, but work is not sufficiently advanced to determine whether or not the correlation is simple or indirect.

A promising indication of the value of model work in this connection has recently been given by the performance of the single-uptake *L* furnace at the Rotherham Melting Shop. Here double roof life may be associated with more uniform flow and low velocities near the roof and back wall.

CONCLUSION

The results given in the present paper show that the flow pattern in an open-hearth furnace is likely to be complex and is appreciably altered by certain relatively small changes in design. The patterns obtained on models are very different from those which were thought to exist in full-scale furnaces. For example, it has been found that a substantial part of the gas in the first third of a model furnace is actually moving backwards towards the incoming gas port. Although such recirculation might at first appear quite anomalous, the study of flow in much simpler systems, *e.g.*, those described in Part I, suggests that this is not abnormal ; indeed, it would be surprising if no such recirculation were found in an open-hearth furnace.

Flow-pattern research has now started on a full-scale production furnace under normal operating conditions. The preliminary results fall more closely into line with predictions from models than had ever been expected. If trials on other furnaces show an equally close check it is likely that, within a relatively few years, the construction of a model prior to the building of a new design of furnace will be considered as essential as is now the case with aircraft and ships.

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HISTORICAL NOTE No. 12

The Little Smith of Nottingham

By Dr. H. R. Schubert

IRON workers commemorated by legend and rhyme are sometimes individuals whose existence can be traced in history. We know that "Gentle Johnny Tilsley," glorified by a Gloucestershire ballad, was one of the Masters of the Guild of Wiredrawers and Pinners in Bristol, in the early seventeenth century.[1] Sometimes it is just a name that gives a legendary figure a fixation in history, such as "George a Green," the jolly pinner (*i.e.*, pinmaker) of Wakefield in Yorkshire, who is associated with Robin Hood.[2] Of the "Little Smith of Nottingham," however, not even the name is known. He seems to be a purely legendary character, commemorated by a rhymed couplet such as follows:

> "The little Smith of Nottingham
> Who doth the work that no man can."

When this rhyme was published in seventeenth-century literature, it was generally assumed that the little smith of Nottingham never had existed. Thomas Fuller, who first published the rhyme in 1662, comments: "Who this little smith and great workman was, and when he lived I know not, and have cause to suspect, that this of Notingham is a Periphrasis of Nemo, or a person who never was. By way of sarcasm it is applied to such who, being conceited of their own skill, pretend to the achieving of impossibilities."[3] Fuller, however, had a vague idea that there might have been some foundation in history, when he added: "England hath afforded many rare workmen in this kind whereof he may seem an apprentice to Vulcan." When John Ray, the famous naturalist, reprinted both the rhymed couplet and Fuller's comment, he omitted Fuller's reference to the glory of English smithcraft in the past.[4]

About eighty years later, Ray's interpretation was indignantly rejected by Charles Deering, a local historian of Nottingham. He writes: "Mr. Ray, very probably might not be informed that this Town was once as famous for Hard-Ware of all kinds as Birmingham and Sheffield at present, and that therefore very likely there might be a little Fellow in Nottingham, who might so far excel others in his Branch of Work as to give occasion to this Proverb, which at first may have been applied to Persons excelling many others in their respective Handicrafts, tho' it is now used by way of Sarcasme."[5]

Deering, evidently, had a very good idea of his native town's glorious past in respect of industrial activity. Indeed, so great had been that activity that, in 1257, when Queen Eleanor, the French wife of Henry III, King of England, came to Nottingham, she was soon forced to leave because of the tremendous smoke from mineral coal.[6] As coal was hardly used for domestic purposes, at that period, it may safely be presumed that it was its industrial use that caused the unpleasant fumes.

An important branch of the smiths in medieval Nottingham were the 'lorimers,' *i.e.*, makers of bits, spurs, and iron mountings for bridles and saddles. They were a fairly numerous craft, attaining their highest standard in the fourteenth century. One of the town's streets was named "Lorimer Street" (in Latin, *Vicus Lorimeriorum*) after them; it had become Bridlesmithgate by the sixteenth century.

Among the records preserved in the strong-rooms of the Borough Corporation of Nottingham is an account of a partnership between two lorimers, one John, a lorimer of Nottingham, the other Geoffrey, a lorimer of Lenton, west of Nottingham, dated 13th December, 1385.[7] This is of some interest, as it gives some details of the produce of the lorimers' craft and of the prices paid. The main products were bridles, stirrups and spurs, a pair of stirrups being priced at 4*d.*, a pair of spurs at 12*d.* The lorimers also made locks and keys, a lock and key together being generally priced at 5*d.* For making a plate-lock they were paid 10*d.*, which was the price of one yard of linen cloth at the time.[8] For binding a chest and making a key to the chest, they were paid 10*d.*; in another case, they only received four flagons of ale, priced at 4*d.*, as payment. Of tools used by the lorimers, hammers only are mentioned in the accounts. A hammer for making a bridle was priced at 4*d.*

In the same way as the Lorimers' Street reflected the importance of the lorimers' craft in medieval Nottingham, so the name of the "Great Smith's Gate" (*Vicus magnorum*, or *grossorum fabrorum*) showed the high repute of the town's blacksmiths. Theirs appeared to be the more ancient craft from which the lorimers emerged.

From this information it may be deduced that "the little smith of Nottingham" was quite an important factor in the industrial life of medieval England, but a few centuries later he remained but a figure of ridicule and sarcasm: *Sic transit gloria mundi.*

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Dr. Schubert is Historical Investigator to The Iron and Steel Institute.

[1] *Journal of The Iron and Steel Institute*, 1948, vol. 159, May, pp. 20–21.
[2] J. W. Walker, "Wakefield, Its History and People," 2nd edn., vol. I, pp. 115–117, Wakefield, 1939. The pinner's memory is still recalled by the name of one of London's oldest inns, "The Pindar of Wakefield" in Grays Inn Road, established in 1517.
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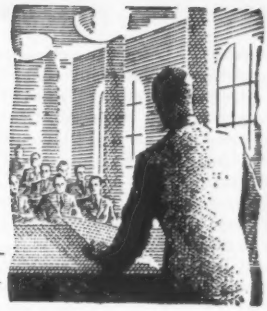
DISCUSSION ON PAPERS



DISCUSSION AT MEETINGS · WRITTEN CONTRIBUTIONS

Autumn General Meeting, 1948

Joint Discussion on the Papers—

OPEN-HEARTH FURNACE INSTRUMENTATION* *by E. Rogers*

FIRST REPORT OF THE OPEN-HEARTH INSTRUMENTS SUB-COMMITTEE†
by F. L. Robertson

Mr. **E. Rogers** (British Iron and Steel Research Association), in introducing his paper, said : When this paper was being written, no definite information was available on air infiltration, so that the approach to the question of air/fuel ratio was rather limited. In order to obtain information, we have since started a series of works trials to study air infiltration on production furnaces. This work is not yet complete, but interesting facts have come to light. Only two furnaces have been dealt with so far, and we cannot extend the conclusions to all furnaces.

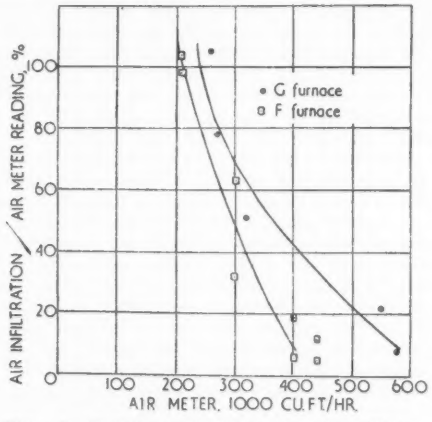


Fig. A—Relationship between air-infiltration and air-meter readings

It is obvious that air infiltration on checkers depends on the pressure inside the checkers and flues, governed to some extent by the throttling effect of the air valve. However, the magnitude of the infiltration between the air meter and air ports is rather unexpected. Figure A is a plot of the percentage of air infiltration against the meter reading ; at full flow there is very little infiltration between the air meter and the air ports, but when the air meter is throttled down the air infiltration goes up to 100%, so that the air flow at the ports remains substantially constant. The theoretical air supply in this case would be about 350,000 cu. ft./hr. Here there is a glimmer of an explanation of the apparently ineffective air/fuel ratio control experiments tried in some works.

Mr. **F. L. Robertson** (British Iron and Steel Research Association) then presented the "First Report of the Open-Hearth Instruments Sub-Committee."

Dr. **A. H. Leckie** (British Iron and Steel Research Association) : Mr. Robertson, and indeed the Sub-Committee, have one main theme—that the ultimate responsibility for running the furnace plant must remain that of the melting-shop manager, and instruments will do nothing to diminish that responsibility. What they do is to ease the load of responsibility for all concerned ; melters, sample-passers, and managers. Our knowledge is not yet adequate to lay down hard and fast rules as to what instruments should be installed first, and the Sub-Committee has taken the only course of recommending a complete list.

One question I would ask Mr. Robertson, is why can so many steel furnaces run successfully without instruments ? This is the point which is so often made by opponents of instruments. Perhaps Mr. Robertson can put the case for instruments a little more practically, and a little more firmly than he has done, for there are many furnaces in this country running without instruments ; however, it is safe to say that they would do much better if they had proper equipment.

Mr. Robertson says that there is no automatic roof-temperature/gas-flow regulator. I think that was true at the time that this report was drafted, but in the last few months, at least one such instrument has been developed, and perhaps Mr. Baker will be able to tell us something about this later on.

One part of Mr. Rogers' paper which I hope will lead to some discussion is his analysis of the reasons why instruments are not universally accepted. Many of us will regret that he has not been able to make firmer recommendations as to whether instruments should be installed all at once or one by one and, if the latter, which should go in first. The relative importance of

* *Journal of The Iron and Steel Institute*, 1948, vol. 160, Sept., pp. 57–72.
† *Ibid.*, pp. 72–74.

certain instruments undoubtedly depends largely on the practice at the plant concerned.

One of Mr. Rogers' most interesting statements is that control and reversal by temperature difference is inherently unsound ; he should elaborate on this a little further. Mr. Rogers has perhaps shown why furnaces apparently run successfully on constant air control. We have shown at the model furnace that it is bad to have excess air, but in practice other factors seem to swamp the effect of excess air. Perhaps one reason why constant air can be used is that if, after melting down with theoretical air, so getting the highest thermal efficiency, the air is kept constant when the fuel is turned down during refining, the resulting excess air gives greater latitude with the refractories at the time when there is the greatest danger, *i.e.*, when refining the steel.

Air infiltration is a serious interfering factor in oil-fired as well as in gas-fired furnaces, I think there could be considerable discussion on the extent to which air meters can be useful under present conditions of brick-work leakage. The importance of metering and recording of waste-gas flow should be emphasized more strongly. The few cases that I have encountered of waste-gas metering have convinced me that this is one of the most important measurements needed for proper furnace operation, and it is relatively easy to obtain.

Mr. Rogers has suggested a particular panel layout ; here, again, it is a compromise between what is technically desirable and what is psychologically desirable from the point of view of the furnace operators.

Attention is drawn to correct maintenance and its difficulties, but I feel that this aspect tends to be a little exaggerated. Admittedly some instruments need a good deal of maintenance if they are to be kept in proper order, but this is largely because the application of instruments to open-hearth furnaces is still in its infancy. As experience is gained it will be possible to design and construct more robust instruments which will run for long periods without any attention.

Mr. Rogers has not said very much about automatic control, but much of the Open-Hearth Instruments Sub-Committee's time is now occupied with problems of automatic control, which is the next logical stage of application. There are already several furnaces in this country working with a considerable degree of automatic control, and in this direction we are likely to see revolutionary changes in steelmaking plant during the next ten years.

Dr. **D. F. Marshall** (Park Gate Iron and Steel Co.) : In the course of yesterday's discussion, reference was made to the undesirability of " blinding with science," and also to the necessity of using common sense as a tool in operational research. Both these statements are particularly appropriate to the subject under discussion. Future progress in instrumentation may depend on the acceptance of the advice given, and on our ability to avoid unnecessary complications.

The application of instruments to open-hearth furnaces can be divided into two distinct categories. We have, on the one hand, the large-scale trials in which one particular furnace may be set up as a research laboratory, as, for example, in the excellent work described in Special Report No. 37 of this Institute (1946). In these cases almost every known instrument is fitted, and the instruments, the furnace operation, and the study of the records will be in the hands of a body of skilled technicians, co-operating closely with the normal plant personnel. Under these conditions furnace performance reaches a very high standard. The results obtained have special significance, because they are really achieved by measurement, and by furnace control based on measurement, with a continuity of control assured by adequate supervision and maintenance.

Most people, however, have to look at the problem from a completely different angle, namely, that of the application of instruments on a complete shop basis. In this case the position is greatly complicated by the large number of furnaces involved. Fewer instruments will be used, and therefore very great care must be taken in the original selection. The staff to deal with the problem will be fewer in number, and they may be less highly skilled than those available for the special trials. Although the conditions are very much more difficult, a good deal of progress can be made if the problem is tackled along the same basic lines as the special research, *i.e.*, with measurement of the right things, adequate control technique, adequate supervision of this technique, continuous maintenance of instruments, and last, but by no means least important, a continuous survey of the records.

The success of any instrument application depends equally on the instrument itself and on the means taken to ensure that it is used efficiently. Both papers give a good deal of help on the first point, but I wonder whether the authors would care to give some assistance on the second point, the question of the supporting organization ?

At Park Gate the instruments which we have installed on our oil-fired furnaces are for measuring fuel flow, air flow, steam flow, roof pressure, roof temperature, and flue-outlet temperature. The installation is based on some very simple principles. The first is that each furnace should have identical equipment, mounted on one central panel, as near to the operating controls as possible. This is extremely important where furnace crews are frequently changed round. The second principle is that particular attention is paid to the incorporation of easily read dials, using recorders wherever possible. The third is the selection of the instruments and the adoption of a standard furnace-operating technique to function in such a way that, in the event of the failure of any instrument on the panel, enough information remains available on the other instruments for the furnaceman to carry on without undue difficulty.

Before we started putting the installation in, the whole problem was discussed with the furnacemen, and the principles of a simplified and standard furnace-operating technique were explained. Detailed instructions for the operation of every furnace were then kept at each furnace. Two members of the staff were assigned to the job on each shift, and one of them helped the furnace crews in learning how to use the instruments. He also used the instruments himself to detect furnace-operating troubles, and supplied reasons, whenever possible, for departures from the standard operating technique. The second man acted purely as an instrument-maintenance man.

After eighteen months' experience, it can be said that the scheme has worked very closely to original expectations. The choice of instruments has proved to be sufficient for the day-to-day operation of hand-controlled furnaces. We have, however, recently installed immersion pyrometers on each furnace. The standard furnace technique, though having certain theoretical limitations, has greatly simplified both the work of the furnaceman and the task of examining the furnace records. The furnace crews have responded extremely well to the system, due, we consider, to the simplicity of the methods adopted, and to the 24-hours-a-day organization for supervision and maintenance. Finally, the detailed study of the records produced has given the management invaluable information on shop operation, the process itself, and the performance of the individual furnaces.

Mr. **N. H. Polakowski** (University College, Swansea): I have seen in the Röchling-Buderus Steelworks, Wetzlar, Germany, a small (35-ton) open-hearth furnace of a very up-to-date design producing high-quality steels. It is fired by cold coke-oven long-distance gas from the Ruhr area, enriched with tar vapours from an adjacent installation. Is it possible to measure the gas/tar-vapour ratio continuously? My reason for asking this is that the following problem may occasionally arise.

The gas mains are often overloaded, and sometimes, especially in cold periods, the pressure of the gas may drop. Is it possible to regulate the ratio of the gas to tar vapour, say, by regulating the temperature of the tar vaporizer (obviously keeping the ratio below the point of saturation, as otherwise the tar would condense on the walls of any cooler pipes) so as to maintain an approximately constant calorific value of the mixture and at the same time a constant temperature of the furnace, which is also of importance for heating furnaces for ingots, billets, etc.? If it is possible, does such an apparatus exist?

Dr. **J. H. Chesters** (United Steel Companies, Ltd.): As the new Chairman of the Open-Hearth Instruments Sub-Committee, I take this opportunity of expressing to Mr. Robertson the thanks of the Sub-Committee and of the industry for the pioneer work that he has done. I should also like to say a word about the policy of the Sub-Committee. We can divide our future programme into three parts. First of all, we want to consolidate our position by stating what we know in a handbook of instrument practice, with particular reference to open-hearth furnaces, which we hope will be available next year.

Secondly, there are certain instruments (personally, I would put roof-temperature and furnace-pressure as the main ones) regarding which we need a great deal more fundamental information. The roof-temperature measuring devices, at the moment, work excellently, and some have worked for six months without any change of calibration, but we do not know exactly what they are reading. Additional work has therefore been started, and Mr. Hall of the National Physical Laboratory may like to say a word about the future programme of the Pyrometry Sub-Committee on roof pyrometry.

Another item required is some instrument for measuring flame power. At the moment we have to look at all the instruments and integrate in our heads.

The third part of our programme is automatic control, and that will be the main item for the next five years. There are half a dozen systems on order in this country, and several have already been installed; the results look encouraging, but we dare not say more than that. In one of our works a roof-temperature/oil-flow link has been installed. It has given no mechanical trouble, but there are certain snags, *e.g.*, badly piled scrap throws the flame into the site hole, whereupon the instrument registers a very high temperature and cuts the oil down just when a high temperature is wanted. On one occasion, during refining, we saw that the roof temperature was constant, but that the oil was being turned on. That was found to be due to the charging of fluorspar, which created a dense fume and reduced the reading of the instrument. There are many such problems, and the study of them should prove quite exciting.

To ask a leading question, with cold scrap furnaces, ought we to work throughout the whole period with a link between the roof temperature and the oil or gas flow, or ought we to go on the basis that, in the early part of the period, the roof temperature measurement is unreliable, owing to things like flame deflection, so that we should work with a fixed flow using a stabilizer that gives, say, 300 gallons to start with and 350 a little later, and which is replaced by a roof temperature link only when the charge is melted down?

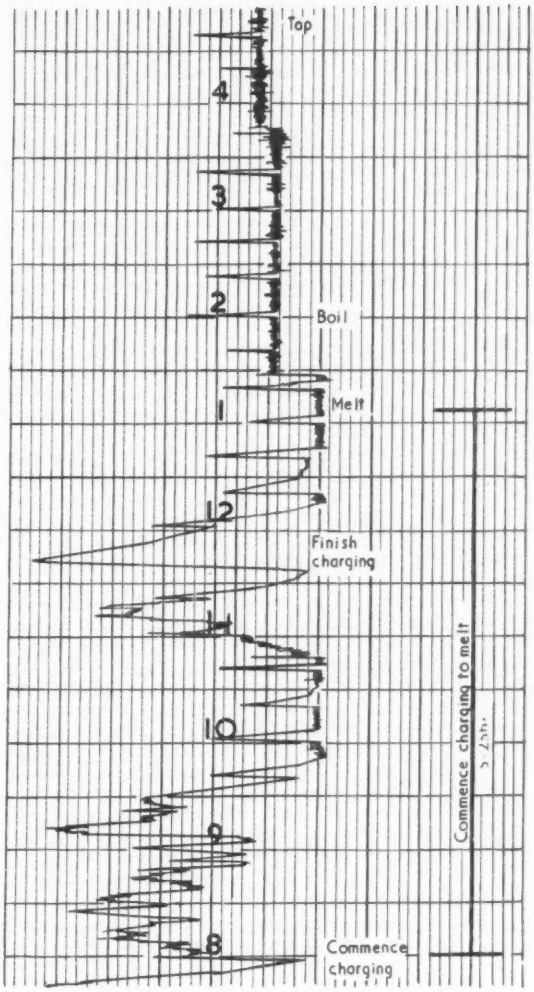


Fig. B—Results achieved with automatic roof-temperature/gas-flow control

Mr. **R. C. Baker** (Baker and Bessemer, Ltd.): Mr. Robertson advises young melters to use measurement and automatic regulation. This brings up difficulties in some larger firms, where a complete layout has to be chosen in conjunction with some other department, and leads to delay. If a melting-shop manager can obtain the more necessary instruments and install a few without waiting for a decision concerning the whole plant, this delay can be minimized.

It is stated that there was no automatic roof-temperature/gas-flow control on the market at the time of the report. This position has now been altered, and the type of result which can be obtained on a producer-gas-fired furnace is shown in Fig. B. This represents a complete charge, from charging to tapping. In the charging period the controller keeps the gas at a predetermined flow. The temperature is then maintained at the maximum until the charge is melted and until a reasonable refining temperature is reached. In order to

avoid too high a tapping temperature, the melter then re-sets his roof-temperature control to a lower figure, and finally to an even lower figure.

One other aspect of instrumentation which requires emphasis, and which Dr. Marshall has already mentioned, is that the instruments must be arranged in such a way that the melters can see and understand them easily. That point is most important, and for this reason it has been found useful to record roof temperature, gas flow, and air flow on one recorder chart.

Mr. Rogers rightly emphasizes the serious effect of air infiltration, and for this reason automatic control of furnace pressure is most important. I cannot, however, agree that gas-uptake pressure is of secondary importance, as this measurement, at a given gas flow, gives an immediate indication of gas-port size, which requires frequent maintenance in order to maintain high melting rates.

Mr. **R. Jones** (John Summers and Sons, Ltd.) : In my early days at the melting shop, I was so continuously harassed by my superior as to the reasons for irregular occurrences, especially on the night shift, that I resolved there and then that there could surely be only one answer to the problem. The answer, planned instrumentation, has been so successful from every point of view that we are now looking forward to the time when the only matters we have to deal with each morning will be lapses outside the melter's jurisdiction, such as machinery breakdowns.

Every melting-shop manager without instrumental control on his furnaces is in a similar position to that in which I found myself prior to the introduction of furnace instrumentation at Shotton, in 1935–36. We have at present a total of 84 instruments for a battery of 8 furnaces at the No. 2 melting shop. This figure does not include gas-plant instrumentation. The charts from all furnaces in commission are set up in suitable cabinets in my office by 9 a.m. each morning, and cover the previous 24 hours' work. Any deviations from instructions as laid down are dealt with in a suitable manner, and during the last 12 months no instrument has been out of commission for a period exceeding 30 min. This has been achieved with a service and maintenance staff of 12 people, comprising :

- 1 instrument technician, 2 assistant instrument technicians } Staff personnel working days, who also control gas plant instruments.
- 2 men per shift for servicing open-hearth furnace instruments, chart changing, etc.
- 1 man per shift attending solely to taking immersion dips and servicing the immersion pyrometers.

My advice to managers contemplating instrumentation would be to install, in the first place, such instruments as will help them to overcome their peculiar managerial and plant difficulties. Having installed an instrument, ensure that it will be correctly serviced and put under managerial control immediately. This advice is contrary to that given by Mr. Rogers.

I am of the opinion that Mr. Rogers' paper would have been of much more value had the introduction under the headings " Application of Instruments in Melting Shops," and " Correct Use of Instruments," been omitted. For example, I cannot conceive that a melting-shop manager should be asked to accept an instrument. Surely the manager must be, himself, the instigator and prime mover in the management of his shop, and hence in the introduction of instrumental control ? Then the statement that no manager should install an instrument without an attempt to explain its purpose to the men prompts me to ask, with apologies to the originator of that well-known phrase, " What kind of people do they think we are ? " Nevertheless, the general substance is good, and will give any energetic manager a start on the sound principles of open-hearth furnace instrumentation.

I am rather surprised to note that in both papers the instrument for recording the gas-port pressure is placed in the secondary class. This is, in my opinion, an essentially primary control to assist the manager in ensuring that the gas-port characteristic, as constructed, is maintained. This is very important from a production aspect, and I should be pleased to hear Mr. Rogers' and Mr. Robertson's views on this point.

Mr. **J. A. Hall** (National Physical Laboratory, Teddington) : As Dr. Chesters has indicated, we have started on a programme of investigating what is the real significance of the readings given by the roof pyrometer. To do that, we are adopting the photographic technique which I described to this Institute in another connection two years ago,* and adapting it to an exploration of the brightness of open-hearth furnace roofs. I showed some roof results a year ago in a discussion on a paper by Mr. Land. We have now made a start, however, in using the cinematographic technique ; the results, so far, generally confirm what I said a year ago.

I should like to express, from the other side of the fence, my complete agreement with Mr. Robertson's remarks. Speaking as a physicist, I appreciate that the ultimate aim is not the attainment of another decimal point in precision, but the improvement of the working of the melting shop.

CORRESPONDENCE

Mr. **R. E. H. Williams** (The Wellman Smith Owen Engineering Corporation, Ltd.) wrote : At the time when Mr. Robertson completes his Chairmanship of the Open-Hearth Instruments Sub-Committee, I should like to pay my tribute to him for the magnificent pioneering work which he sees so well established today.

In 1938, I had the privilege of visiting the Shelton open-hearth shop. At the time, I was particularly interested in refractory materials, and Mr. Robertson spoke to me with enthusiasm of his ability to tell me which were the three best British silica bricks for open-hearth roofs, in order, classified according to the maximum temperature that roofs of each brick would stand, as measured by roof-temperature pyrometers. In view of the almost innumerable differences of opinion held in the industry concerning the relative merits of the available supplies of this refractory, it seemed incredible that any melting-shop manager could be so dogmatic. It occurs to me now, that Mr. Robertson's roof-temperature pyrometers must have registered a somewhat higher than true reading, because (speaking from memory) I believe that his ' best ' brick could reputedly be taken to 1705° C. This is said in no spirit of churlish criticism, because it was soon apparent to me that whether or not his roof pyrometers gave accurate readings, they certainly recorded what mattered to the melter, namely, a point beyond which it was dangerous to attempt to take a roof. My conversion was completed when Mr. Robertson altered the producer-gas flow on one of his furnaces and the response of the corresponding roof-temperature pyrometer was almost instantaneous. It occurred to me, then, that perhaps the greatest value of roof-temperature pyrometry lay, not so much in the preservation of the roof, as in the opportunity afforded to the melter of utilizing his fuel and air supplies to the best advantage. I deliberately refrain from saying " to save fuel."

This experience was nearly 11 years ago. Such experiences are commonplace in many shops today, though

* *Journal of the Iron and Steel Institute*, 1947, vol. 155, Jan., p. 55.

not in all ; but I believe that long after Mr. Robertson has ceased to make steel, his name will be remembered by a great many students of steelmaking as a real pioneer, with the increasingly rare attribute of being fanatically scientific, but with feet firmly planted all the time on the melting-shop stage.

It is interesting to see that Mr. Robertson has applied the technique developed at Shelton to the furnaces at Shotton, where the tapping temperatures are so much higher and prolonged. It would appear that roof-temperature pyrometry could be of considerable assistance to acid and basic furnaces, where a high percentage of casts are made which give ' stiff ' melting slags. With the increasing tendency, during the last decade or so, to use greatly increased quantities of fuel and air input during the charging and melting periods there is a real risk of roof damage when making, for example, high-chromium charges. Perhaps this even applies to Mr. Robertson's furnaces at Shotton when making low-carbon rimming steels from cold pig and scrap, specially when the furnaces have lost their newness ?

It would be interesting to learn the views of Mr. Rogers and Mr. Robertson concerning the possibility of measuring the temperature of open-hearth furnace hearths at various levels. The pros and cons of hearth insulation might be more clearly evaluated if information from such measurements was available. The value of such information to shops making 0·06% carbon steels, Armco, and electrical quality, seems obvious.

Mr. **F. J. Cunningham** (George Kent, Ltd.) wrote : With regard to raw-producer-gas flow measurement, we would like to correct the impression given by Mr. Rogers (p. 65 of his paper) that measurement in horizontal mains cannot give satisfactory results. Actually, we have three installations where horizontal venturi tubes have, of necessity, had to be used, and where we have been assured that satisfactory metering is being obtained.

It is agreed that the vertical location is to be preferred whenever the plant layout permits this, and specially where the gas is of low temperature and where heavy deposits are likely to be encountered.

Reference is made in the paper to records of roof temperature, gas, and air flows on one multipoint recorder chart. It may be of general interest that we have developed a recorder to provide six different instrument readings on one chart of 10 in. width, and these readings may include furnace pressure, gas pressure, gas temperature, or air checker temperatures, as required.

Oil-flow measurement was briefly dealt with by Mr. Rogers, but it may not be generally known that the standard square-edged orifice plate is unsatisfactory for measuring medium- and heavy-grade fuel oils. Many years ago a special orifice plate was developed for such oils and this is being generally used in many open-hearth installations operating on oil fuel.

The important feature is that the discharge coefficient for this special orifice plate remains constant for all flows and viscosity values within the working range of the meter.

AUTHORS' REPLIES

Mr. **Rogers** (in reply) : There is an additional argument which can be advanced to support reversal by time interval. After the fettling period the regenerators are usually ' out of balance.' When charging is commenced, and the furnace is reversed on a time basis, it is found that the regenerators are balanced after four or five reversals. The furnace is then fundamentally stable. Permanent out-of-balance conditions are an indication that something is wrong.

Mr. Jones prefers to institute strict managerial control from the moment an instrument is installed. In a large number of works, it has been more general to build up a system of instrument discipline over a few months, as the melters become more experienced in the use of clock readings.

Gas-uptake pressure is, strictly speaking, a secondary control instrument, as it provides information which is available on the primary instruments, in a different form. The measurement is one of the most important secondary instruments and can well be upgraded.

Mr. **Robertson** (in reply) : I should like, first of all, to thank all the speakers for their very kind remarks regarding my report. I would like to enlarge on most of what has been said, but I will attempt to limit myself to replying to specific questions.

Dr. Marshall's queries regarding the supporting organization have, I think, been amply dealt with, both by his own suggestions and by those of Mr. Jones. Dr. Marshall's shop is one of those which I love going into, because the instruments are always in order.

Dr. Leckie asks why it is that some furnaces run quite well without instruments. I made thousands of tons of steel, myself, before I started getting interested in instruments some 15 years ago. I do not think he is seriously querying the value of instruments, and I can best answer him, perhaps, by saying that when I was a boy in Ireland no children wore shoes and stockings, but today they all wear them.

There have been several references to automatic control, and I am convinced that this has a great future. There are already three such installations in operation, and we hope to have a second one installed within the next few weeks. According to the managers of the shops concerned, the performance of these controllers is remarkably good and they require very little attention. One such installation, in Mr. Jones' shop, has been working satisfactorily now for some six months. This particular installation has three roof pyrometers all controlling the oil flow.

With regard to Dr. Chesters query ; I am not in favour of stabilized flow as an alternative to a roof-temperature/fuel-flow link, since I consider that stabilized flow involves at least as big a risk of damage to the roof.

The rapid progress in automatic control is illustrated by the fact that, at the time of my report, there was no roof-temperature/gas-flow installation on an open-hearth furnace, but Mr. Baker now reports that they have such an installation working and that it works very satisfactorily.

Dr. Polakowski raises the question of whether automatic control could be used to regulate the ratio of coke-oven gas to tar vapour. This might be a rather tricky problem in instrumentation, but I feel sure it would not be beyond the brains of our friends in the instrument industry. Automatic regulating of fuel ratios has already been tackled, and the combined flow can always be adjusted in terms of the roof temperature.

With automatic control we start to be interested in changes of the order of even 5° C., and this immediately raises the question of just what the roof pyrometer is measuring. We are very glad, therefore, that Mr. Hall is making a study of brightness variation over the roof, and look forward to a report from him on just how much of this variation is real, and how much merely due to mirror-like reflection of light from the flame.

In reply to Mr. Williams' written contribution, I would agree that the conditions at Shotton are particularly severe, since we are making low-carbon steels which require a high tapping temperature, and doing so with a particularly large slag burden. Roof pyrometry, under such conditions, becomes particularly important if the last ounce is to be got out of the furnace.

The measurement of hearth temperature, although, doubtless, possible, does raise a number of difficulties, in particular the risk of couples becoming contaminated by iron oxide and the risk of a breakout due to the presence of a channel in the hearth. Similar work has been done on blast-furnaces, but the results have often been ambiguous, and there is no doubt that a special technique is required for this sort of work. The importance of maintaining a reasonable temperature gradient through the hearth was shown in connection with work carried out by the Basic Furnace Linings Committee. The working face of the hearth which had been over-insulated was found, on tapping, to be in an extremely pasty condition, making proper drainage almost impossible and resulting in a marked increase in the amount of dolomite fettling used per ton of steel made.

Discussion on the Paper—

RAPID ESTIMATION OF SLAG BASICITY*

by W. A. Smith, J. Monaghan, and W. Hay

Mr. **W. A. Smith** (Messrs. Stewarts and Lloyds, Ltd., Coatbridge) introduced the paper.

Mr. **W. L. Kerlie** (Messrs. Stewarts and Lloyds, Ltd., Corby) : Apart from its practical aspects, this paper has also a fundamental significance which is brought out by an extended examination of the data. The authors are careful to point out on page 130 that : " No attempt is made to explain why it should be possible to estimate the slag V ratio so closely by the conductance method . . ." An approximate equation connecting V ratio and conductance has been established. This equation is clearly empirical and represents the simplest and most practical interpretation of the data. I have no criticism to make concerning this procedure, but would like to bring the attention of the authors to the following points with the hope that, in this way, some light may be thrown on the meaning of V ratio.

I have plotted the V ratios and conductance values of Table VIII in Fig. A ; a series of broken lines through the maxima and minima correspond to the V ratios 1, 1·5, 2·0, and 3·0, which are approximately the values for $CaO.SiO_2$, $3CaO.2SiO_2$, $2CaO.SiO_2$, and $3CaO.SiO_2$, respectively. This suggests that the V ratio is of more than practical significance.

Figure B, a logarithmic plot of V ratio and conductance, corresponds to Fig. 7 in the paper. Although a straight line could be drawn through the points as a straightforward practical measure, it would appear that a series of curves corresponding to the concentrations of the various silicates and the straight lines of Fig. A might well be a better fit—this is a problem for the statistician—and the figure suggests that the conductance of a water extract varies directly as the V ratio, and

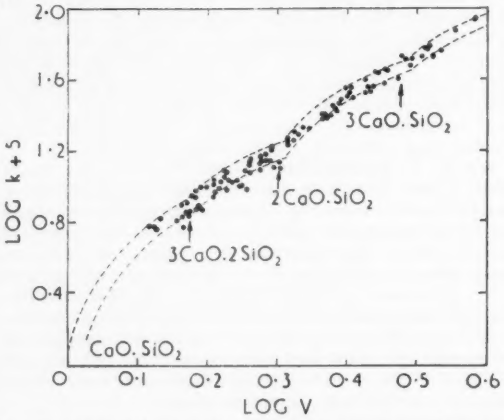


Fig. B—Logarithmic plot of V ratios and conductance

is related to the type of silicate and/or phosphate present in the slag and undergoing dissociation and hydrolysis. Confirmation of this might lie in an examination of the meaning of the V ratio, as follows :

$$V = \frac{CaO}{SiO_2 + P_2O_5} \qquad \frac{1}{V} = \frac{SiO_2 + P_2O_5}{CaO}$$

$$\therefore 1 - \frac{1}{V} = 1 - \frac{SiO_2 + P_2O_5}{CaO}$$

$$\frac{V-1}{V} = \frac{CaO - SiO_2 - P_2O_5}{CaO}$$

On a molar basis and assuming that $CaO.SiO_2$ and $3CaO.P_2O_5$ are essentially neutral and stable :

$$V_{mol} = \frac{CaO}{0{\cdot}933SiO_2 + 1{\cdot}184P_2O_5}$$

$$\frac{V_{mol} - 1}{V_{mol}} = \frac{CaO - 0{\cdot}933SiO_2 - 1{\cdot}184P_2O_5}{CaO}$$

$$= \frac{(CaO)}{(\Sigma CaO)}$$

which is the ratio of free lime to total lime, or the active-lime fraction. The term $(CaO - 0{\cdot}933SiO_2 - 1{\cdot}184P_2O_5)$ is Herty's B value for basicity.

As shown in the following list of values, the V ratio for each of the various compounds is roughly the same as the V_{mol} ratio :

* *Journal of The Iron and Steel Institute*, 1948, vol. 160, Oct., pp. 121–130.

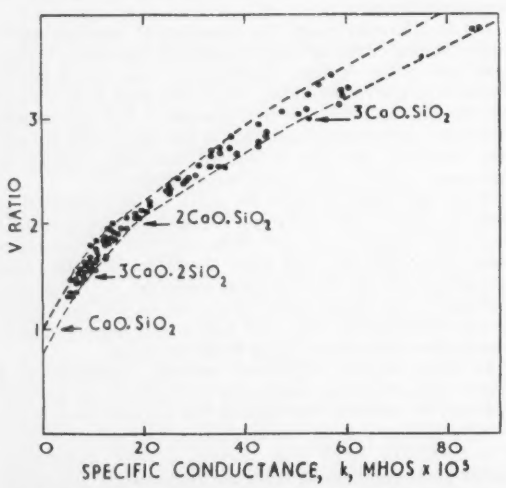


Fig. A—V ratios plotted against conductance

	V_{mol} Ratio	V Ratio
$3CaO.P_2O_5$	1·0	1·18
$CaO.SiO_2$	1·0	0·93
$3CaO.2SiO_2$	1·5	1·40
$2CaO.SiO_2$	2·0	1·87
$3CaO.SiO_2$	3·0	2·79

With basic open-hearth slags, in which silicates and phosphates are present, the V ratios and V_{mol} ratios are essentially identical.

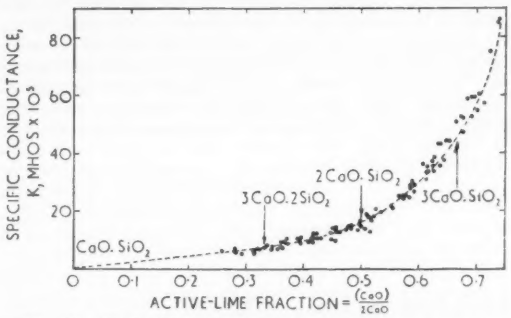


Fig. C—(CaO)/(ΣCaO) plotted against conductance

If the active-lime fraction is denoted by X :

$$\frac{V-1}{V} = X, \text{ or } V = \frac{1}{1-X} = 1 + X + X^2 + X^3, \text{ etc.}$$

This means that as X tends to zero, V tends to unity and that as the slag tends to pure lime ($X = 1$) the V ratio is infinity. On plotting X, *i.e.* (CaO)/(ΣCaO), against conductance, as shown in Fig. C, a curve of this type is indicated, but with possible changes in directionality for the various silicates.

The term covering the basicity of all slags (acid, basic, or neutral) is :

$$X = \frac{V_{mol} - 1}{V_{mol}}$$

For basic slags, V is greater than unity, and X is therefore positive ; for neutral slags $V = 1$ and X is zero, and for acid slags X is negative, as shown in Fig. D. This diagram may be said to represent, in a crude way, the average value per mol of a property (Y) plotted against the mol fraction (X), but the influence of MnO, MgO, Al_2O_3, etc., will require consideration and would require to be determined by experiment, and then the true molar values calculated from the slag constitution.

If melts were made from lime and silica and also from lime and P_2O_5 in varying proportions and conductance

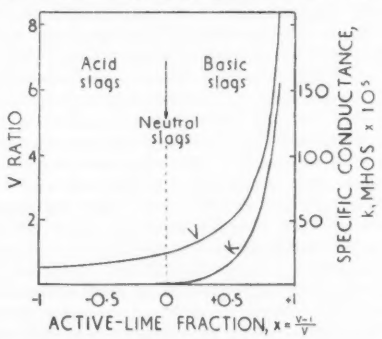


Fig. D—Representation of the average value per mol of a property (Y) plotted against the mol fraction (X)

tests were carried out on water extracts, it would be possible to confirm these findings.

Mr. **F. L. Robertson** (Messrs. John Summers and Sons, Ltd.) : An effort like this, to reduce the time gap in furnace chemical control, is welcome. Twenty-five minutes furnace-to-furnace time is as good as anything we can yet get ; to obtain 95% right answers to the slag basicity question is quite good enough.

Would the authors tell us what use they propose making of this knowledge of the basicity on the stage ? During my steelmaking life I have gradually thought less and less in terms of basicity and now, though I know that my slags are basic, I do not control in those terms.

There are four aims in chemical control of the two liquid systems where basicity plays a part. I have, however, found other controls easier to apply, even though they may bring about a greater basicity. These aims are :

(1) To keep the phosphorus within the specification ;
(2) to keep the sulphur under specification ; and
(3) to raise the residual manganese.

I leave out the very difficult and intricate question of control of the rate of carbon drop by basicity.

For phosphorus control I have for the last 15 years found that Schenck's phosphorus equation is all the control I have needed for keeping the correct lime, silica, and P_2O_5 concentrations in the slag :

$$\text{Log P} = \log K^{1V}_{p} + \log (P_2O_5) - 5 \log (FeO) - 4 \log (CaO) - 0{\cdot}06(P_2O_5)$$

I have used this whether I was working the charge down soft or catching the carbon high. Regular shop practice for a given carbon produces a regular 5 log (FeO). Too high a phosphorus at any given carbon means only one thing, and that is that the 4 log (CaO) is not high enough. The weight of this lime can be calculated, as also can the amount of phosphorus still to be removed. It is in this field that I suppose the authors will prefer to use their basicity control.

We used to be bedevilled by thinking basicity worked a charm on removing sulphur, but it is only partially true. Desulphurization of the steel depends on the partition ratio of sulphur between slag and steel, the relative weights of slag and steel, and the total weight of sulphur in the two liquid systems put together. In actual practice at the furnace we now desulphurize quantitatively to the degree we can afford without a thought about basicity. We determine the slag weight by the ingoing phosphorus tonnage and the P_2O_5 in the slag, or by the ingoing lime only. We determine the sulphur partition by direct analysis of sulphur in the slag and the steel. We then calculate the slag weight required and make it.

In the making of the increased slag weight, addition of lime alone is apt to be too basic, and therefore insoluble, and so at times silica is added. I can see that keeping track of the silica content might be a very useful chemical control and, as we know the phosphorus and lime charged, the authors' basicity figure would give us the silica.

I hardly need mention the effect of basicity on residual manganese, except to ask the authors whether they attach sufficient importance to high residual manganese to force the basicity up in order to get a little more residual manganese for any given manganese in the liquid systems.

AUTHORS' REPLY

Mr. **Smith,** Mr. **Monaghan,** and Mr. **Hay** wrote in reply :

Mr. Kerlie has drawn attention to some theoretical implications of the data which we have presented.

While carrying out this work we were pressing for a quick and accurate method of measuring basicity, and on the theoretical side we permitted ourselves only the most sketchy speculations. Mr. Kerlie's comments are therefore welcome, and will be examined as further data accumulate.

Mr. Robertson's request to say what use we propose making of this knowledge of basicity on the melting-shop stage, might well be the subject for a separate paper, and indeed such a paper* has already been submitted to the West of Scotland Iron and Steel Institute. In brief, however, we did not find the method of charge control practised by Mr. Robertson sufficiently accurate, because of variation in our raw materials. These variations can be discounted by starting control at clear melt, but it is obvious that very rapid methods of analysis are then necessary to enable control to be effective. The conductivity method serves as a reasonably quick and accurate check on the 'pancake' estimation of basicity.

Sulphur removal presents no difficulty with the raw materials at present available to us, so that we are unable to comment on Mr. Robertson's practice. So far as manganese is concerned, we do not adjust basicity with the deliberate aim of increasing the residual manganese, but the iron oxide in the slag is kept as low as possible for other reasons, and this, according to all the rules, should give a reasonable manganese recovery.

*J. Monoghan, *Journal of the West of Scotland Iron and Steel Institute*, 1948–49, vol. 56.

Discussion on the Paper—

A MAGNETIC STUDY OF STAINLESS STEEL WIRES*

by P. T. Hobson, E. S. Chatt, and W. P. Osmond

Mr. **W. P. Osmond** (Messrs. Boosey and Hawkes, Ltd.) presented the paper.

Mr. **D. A. Oliver** (Messrs. Wm. Jessop and Sons, Ltd.): I have had some experience of the breakdown of stainless steels from the austenitic to the ferritic condition by cold work. It is well known that this occurs when the steel is starved of alloy, and it is understood that the 18/8 material should not be fully austenitic at all if made in a pure form and the nitrogen and other impurities are kept to a low value. It might be 50% austenitic and 50% body-centred cubic. Industrial alloys have sufficient impurities to make them sensibly austenitic when fully heat-treated, but there is always a tendency for this α-phase to reappear, and in cold drawing that is exactly what happens.

The first point which arises is how this α-phase is distributed radially in the wire. Jay,† experimenting with 18/8 cold-worked wires, etched off the surface layers, X-rayed them at intervals by glancing-angle technique, and managed to study the distribution of the α-phase in the cold-worked wire. I think that the results were sensibly in agreement with the information given in conclusion (4) in the Appendix to this paper (p. 156), where the surface contained rather less α than the core.

The next question is whether the α-phase is in volumes of widely varying size, or whether it is precipitated in more or less uniform ellipsoids, or similar shapes. My own view is that they must have a statistical size distribution, and probably the size distribution varies strongly with the radius. One would expect, I think, rather larger volumes near the core of the wire than near the surface.

The chemical compositions of these steels are quoted with too much tolerance. It matters a great deal whether it is 12·1% or 12·3% nickel, and whether it is 11·9% or 12·4% chromium; in their reply the authors should, if possible, give the analyses to at least one place of decimals, including the exact carbon contents of the steels.

This 12% nickel–12% chromium steel is known among alloy steelmakers as the 'watchcase steel,' because it is more ductile than 18/8. It takes a high polish, being richer in nickel. The nearest experience which I have had to this particular steel is in studies of the austenitic valve steel DTD 49B, which, however, contains 0·4% carbon, as distinct from 0·1%. When this steel is austenitized, having a 12/12 nickel–chromium composition, it is right on the borderline of the phase boundary, and α readily appears with cold work. To reduce this tendency I should expect the sum of the nickel and chromium to be at least 25%, so that if one had 12% nickel one would want 13% chromium, in order just to cross the phase boundary. Thus the steel which the authors studied was just on the side of the boundary where ferrite can be expected to appear readily.

The analysis in the paper is rather bold, and for this reason, I do not know whether to accept it or not. Most of the phenomena under discussion are statistical distributions, and no evidence is given as to whether they are sharp-peaked or broad-peaked functions. Some of the assumptions made appear to need further painstaking experimental work to put them beyond question.

The authors have put in a large number of empirical adjusting factors because close agreement was not obtained. I think that these factors are undesirable, and within the reliability of anything that can be deduced from the magnetic analysis, the adjusting factors might even hinder interpretation. When one analyses the magnetization curves, one has to start off with a large number of simplifying assumptions, and it should not be expected, after a devious argument, that everything will be in perfect agreement at the end. As mentioned previously, the radial distribution of this α-phase has been completely neglected, and little is known about its size distribution. Yet the agreement in diagnosing those crystals which are oriented in particular ways is certainly very striking.

The magnetic testing apparatus referred to is going to be very valuable for controlling wires of this sort. I was also very interested in Mr. Osmond's point that what matters in the recording of sound on steel wires is the ratio of the coercive force to the remanence of the steel. At first sight that seems wrong, but it must be remembered that sensitivity is of minor importance, and a

* *Journal of The Iron and Steel Institute*, 1948, vol. 159, June, pp. 145–157.

† A. H. Jay: Unpublished work.

10 : 1 loss in voltage can be readily restored by amplification. If the α-phase particles are discrete little permanent magnets, buried mechanically in a non-magnetic austenite matrix, it is easy to see why high coercivity and low remanence give permanence of record by resisting self-demagnetization, as well as establishing weak leakage fields at appreciable distances from the particle. The process of cold working enables a wire to be made with thousands and thousands of little permanent magnets buried in it end-to-end, spaced, and varying in radial distribution. When a very fine-pitched magnetic wave is superimposed on to it during recording, the particles are magnetized in the direction of cold working (which is a preferred direction), and they have sufficient coercivity to resist demagnetization. They are widely enough spaced to enable a small pole-piece to pick up again the leakage field round each little magnet for reproduction purposes. Would the authors agree with this possible picture of the process ?

Mr. G. C. Richer (The Steel Company of Wales, Ltd.) : It naturally gave me great pleasure to find that the authors had been able to make such encouraging use, in such a novel field, of my exploratory interpretation of the magnetization curve, published some four years ago by the Institute,* and that they had not missed my two or three lines of warning that the principles of what I called ' trichotomy,' were likely to be more important than numerical illustrations based on conventional models of the ferromagnetic-domain structure. I am afraid, however, that in taking such good note of that warning they have made, as Mr. Osmond has freely admitted, some ' conjectural ' assumptions which may invite the stricture, foreshadowed by Mr. Oliver, that they have just taken a peep at the crib and then faked the right answer. What I particularly want to do, is to give one or two reasons for believing that they have done nothing of the kind.

While the authors were busy, quite unknown to me, in extracting so much from my first thoughts, I myself was busy, quite unknown to them, with the second thoughts that led to the ' probability ' refinement referred to in the Appendix to their paper. This attempt at refinement of the exploratory crudity is based on an analysis of the differential curve, and not of the magnetization curve itself. As the present authors have so usefully shown, differential curves can be much more informative, and much more sensitive, than the integral curves we normally observe, but which we do not yet know how to interpret. For the past seventy years or so, engineers have been making daily use of these integrals without having the foggiest idea of what lies behind them. And not even a mathematical physicist can interpret an integral without first learning how to write down its underlying differentials.

In the development of the probability, or ' differential ' treatment, it has become reasonably certain that, in the hot-rolled electrical sheet steel with which I have been primarily concerned, the total contribution by Barkhausen reversals of anti-parallel domain magnetization, which we can call the ' Barkhausen saturation value,' will be largely independent of the sheet direction along which the external measurements are made. This simply means that it will tend to be independent of the distribution of crystallographic orientation. This conclusion is based on a considerable volume of experimental evidence, and its validity is in no way dependent, either on the validity of the treatment adopted, or on the precise mental picture we form of the ' reversal ' mechanism that operates over the steep part of the magnetization curve, *i.e.*, up to the point at which the present authors' B_r–H curves become horizontal. On this basis, we can make an interesting little calculation about the demagnetized domain structure.

It is generally accepted that in the demagnetized state the domain magnetization will tend to align itself parallel to [100] cubic crystal directions, *i.e.*, parallel to cube edges. This will mean that under ' 111 ' conditions of magnetization, *i.e.*, with the external field parallel to an internal cube diagonal, the symmetry of the cubic lattice will give

$$B_{rs[111]} = (B - H)_s/\sqrt{3},$$

where $(B-H)_s$ is the familiar ferric induction saturation value, which will be a structure-insensitive characteristic for any given ferromagnetic, and where $B_{rs[111]}$ denotes the Barkhausen saturation value under ' 111 ' conditions.

But if, under ' 100 ' conditions of magnetization, *i.e.*, with the external field parallel to a cube edge, we are to have

$$B_{rs[100]} = B_{rs[111]},$$

then there must exist, in an idealized ' 100 ' crystal-group, a measure of preferred domain orientation, about the direction of external measurement, represented by the factor

$$1/\sqrt{3} = 0 \cdot 58.$$

Similarly, in an idealized ' 110 ' crystal-group, with the external field parallel to a cube-face diagonal, we cannot have

$$B_{rs[110]} = B_{rs[100]} = B_{rs[111]}$$

without a preferred domain orientation factor of

$$(1/\sqrt{3}) \times \sqrt{2} = 0 \cdot 82.$$

For the ' 111 ' crystal-group the domain orientation factor will, of course, be

$$(1/\sqrt{3}) \times \sqrt{3} = 1 \cdot 00.$$

Estimates of this kind will obviously reflect the principles on which the reconciling assumptions of the present paper could have been based, and in spite of the fact that, in the authors' experimental material, the ferromagnetic constituent can hardly be expected to behave in quite the same way as hot-rolled sheet steel, it is interesting to note that by using arguments which, as Mr. Oliver has suggested, can at first sight be suspected of too large a content of " empirical adjustment," they have arrived at orientation factors of a remarkably similar order. In their first worked example, for instance, instead of the ' ratio ' series given above by

$$0 \cdot 58 : 0 \cdot 82 : 1 \cdot 00,$$

the authors have shown that by defensible application of magnetostriction data, recorded on yet another type of ferromagnetic material, *viz.*, highly oriented cold-reduced silicon strip, they can deduce, and credibly apply, the series

$$0 \cdot 54 : 0 \cdot 77 : 1 \cdot 00.$$

I feel almost certain, therefore, that " empirical adjustment " has not led them very far wrong, and that the ultimate verdict will be that the assumptions they have made are quite soundly conceived. Faraday never hesitated to ' stick his neck out,' or, as he phrased it, to ' commit himself beyond what present facts will sustain '; and I think the authors are to be congratulated on the promising results they have been able to put before us by having had the courage to follow such a worthy example.

CORRESPONDENCE

Mr. W. C. Heselwood and Dr. **K. W. Andrews** (Research and Development Dept., The United Steel Companies,

* *Journal of The Iron and Steel Institute*, 1944, No. 2, pp. 93P–142P.

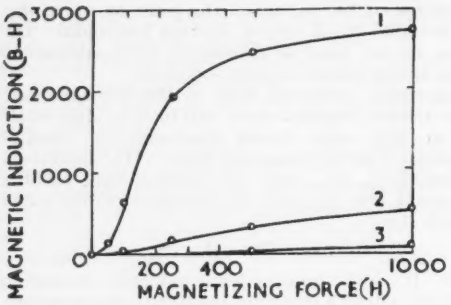


Fig. A—Magnetization curves of three samples

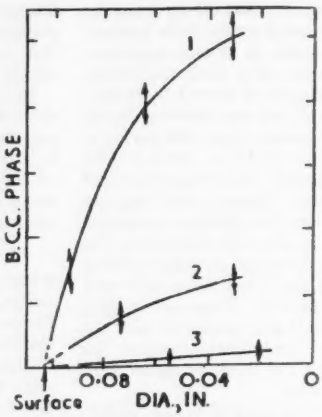


Fig. B—Relation of amount of ferrite (B.C.C. phase), to the diameter of wire, as examined

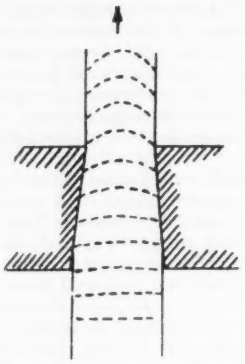


Fig. C—Flow of wire in passing through die

Ltd.) wrote: The authors' results are of considerable interest to us, and we should like to refer to some work done in our own laboratory immediately before the war, and also to part of a more recent investigation.

Some stainless steel wires, examined in connection with the supply of non-magnetic wire for chin straps for steel helmets, were found to have varying degrees of magnetization, depending upon the composition and treatment. Five steels examined had the following compositions:

	Steel 1	Steel 2	Steel 3	Steel 4	Steel 5
Carbon,% ...	0·08	0·08	0·07	0·08	0·08
Manganese,%	1·84	1·75	0·48	0·50	0·46
Silicon,% ...	0·41	0·455	0·41	0·455	0·44
Nickel,% ...	7·88	9·24	11·60	9·14	10·10
Chromium,%	18·88	18·56	18·28	19·00	18·48

The steels were in the cold-drawn condition, having been subjected to an 82% reduction in area, with final dia. of 0·102 in.

The magnetization curves for the first three of these wires are shown in Fig. A. The curve for steel 5 is very near to that for steel 2, and the curve for steel 4 somewhat lower than for steel 1. The steels 1, 2, and 3 were submitted to a more detailed examination.

An X-ray examination was carried out by the late Dr. A. H. Jay. Photographs of the outer surface of each wire showed the presence of the face-centred cubic structure only. By dissolving away the outer layers of the wire in successive stages, it was shown that the ferrite phase was present in increasing amount towards the centre of the wire, as indicated in Fig. B. The estimation of the relative amounts of ferrite (B.C.C. phase), and of austenite, is necessarily somewhat uncertain, but an approximately parabolic variation is suggested by the results.

A possible explanation is based on evidence that, during the wire-drawing process, the deformation is greater towards the centre of the wire, plane sections perpendicular to the direction of flow being transformed into paraboloids, as indicated in Fig. C. If the amount of ferrite produced is more or less proportional to the extent to which the supersaturated austenite is deformed, then a distribution of the form obtained is expected. The presence of practically no ferrite on the outside of the wire, in these particular samples, might be associated with the lead coating lubricant (removed before X-ray examination). A change in lubricating conditions might modify the results.

The effect of temperature on the ferromagnetic properties is shown in Figs. D and E, which relate to steel 1. The lowering of magnetic induction (in a magnetic field of constant strength) as shown in Fig. D, is readily related to the decreasing amount of ferrite, and Fig. E shows the approximate parabolic variation of the

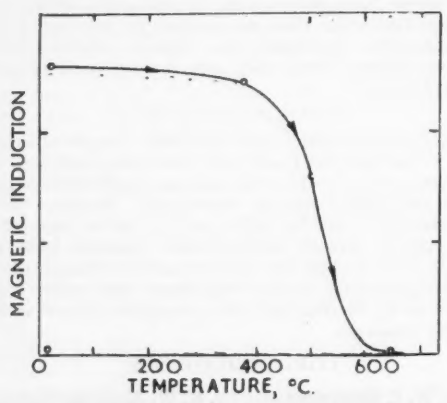


Fig. D—Removal of magnetic induction on heating

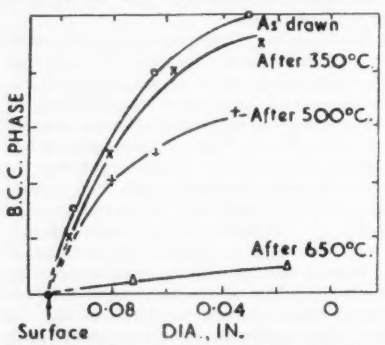


Fig. E—Relation of residual ferrite to the diameter of wire examined, after heat-treatment to different temperatures

amounts of ferrite, with lower total amounts of ferrite after treatment at increasing temperatures.

A recent X-ray examination of a sample of hard-drawn wire of the same type, confirms the increasing amount of ferrite towards the centre of the wire, although, in this instance, a small amount of ferrite is detectable in the outermost layers of the wire, and the amount of austenite rapidly decreases towards the centre. Dissolving away successive layers to the diameters indicated, gives the approximate amounts of ferrite and austenite, as follows :

Dia., in.	Amount of Austenite	Amount of Ferrite
0·055	Large	Small
0·040	Small	Large
0·030	Trace only	Very large
0·020	None detected	Very large
0·007	None detected	Very large

The amount of reduction in area was less than in the earlier samples. This steel was of nominal 18/8 composition, and had undergone a 70% reduction in area in drawing down to 0·055 in.

The austenite constituent in this, and another wire of finer gauge, shows the expected preferred orientation. There is a [111] direction, parallel to the axis of the wire, with a spread of the order of $\pm$ 9°, and some evidence for the subsidiary direction [100] referred to by the authors. The [110] direction of the ferrite phase follows the [111] austenite orientation. There is no marked change in orientation from the outside of the wire to the centre. We hope to carry out a more complete examination of these effects.

The results are obviously in general agreement with those of the authors, and we are glad to see that this interesting topic is receiving attention. The development of a preferred orientation accompanied by a phase change gives the subject a double importance.

AUTHORS' REPLY

Mr. **Hobson** and Mr. **Osmond** wrote in reply : We are grateful for the appreciation of our paper expressed by the contributors to this discussion, and for the amount of information which they have given us about these steels and their properties. Mr. Oliver's suggestion as to the distribution of the ferrite particles, and its confirmation by Mr. Heselwood and Dr. Andrews, quoting the X-ray examination by the late Dr. Jay as well as later similar work, crystallizes our own somewhat vague ideas in a most satisfactory way. It has also been very helpful to learn from Mr. Oliver of the 'trickiness' of the 12/12 alloy, which no doubt accounts for many of the vagaries we found from time to time in sample wires of this composition. As regards the analyses of the alloys, we found, from the production point of view, that we had to come to a compromise between the very strict control that we should like to have maintained and the consideration of what the wire drawers could do for us, and eventually a standard was laid down as follows : tolerance for nickel and chromium, $\pm$ 1% in each case; carbon content, 0·08 to 0·12%.

We agree that Mr. Oliver's remarks on the processes of magnetic sound recording give a very fair picture of what probably happens, with this amplification : the total number of magnetic particles in one half wavelength of the wire behave as one permanent magnet, and the shorter the wavelength the greater the tendency to self-demagnetization ; hence the desirability of high coercivity. We are grateful to Mr. Richer for taking up the cudgels on our behalf as regards the 'wangling' of magnetostriction values to which Mr. Oliver takes some exception. We have always realized that any apparently satisfactory results achieved by such methods need corroboration by further experiment on other lines before complete acceptance.

Discussion on the Paper—

INTERRELATION OF HARDENABILITY AND ISOTHERMAL TRANSFORMATION DATA* *by W. I. Pumfrey and F. W. Jones*

Dr. **F. W. Jones** (Brown-Firth Research Laboratories, Sheffield), presented the paper.

Dr. **L. B. Pfeil** (The Mond Nickel Co., Ltd.) : The Thermal Treatment Sub-Committee of the Alloy Steels Research Committee established, some time ago, a group to consider the undertaking of determinations of **S**-curves on the more important British alloy steels. That group attempted first to assess the value of **S**-curves. I found myself forced to the conclusion that the outstanding merit of such curves, at present, is the qualitative picture they provide of what is going on during the heat-treatment of steel. It was fully appreciated, of course, that an **S**-curve could be used quantitatively in connection with the isothermal treatment of steel, as, for example, when softening for machinability, or when austempering, but **S**-curves provided a qualitative guide only where behaviour during quenching was the problem.

The work carried out by the authors encourages the hope that it may become possible to employ isothermal data more directly to improve our knowledge of what is going on when a steel is continuously cooled. The volume of evidence provided by the authors is, at present, small, and they may have been fortunate in the selection of their steels, or of the specimens on which they worked. The matching of their calculated Jominy curves with the actually determined Jominy curves was fairly good, and perhaps particularly so when the rather large differences in Jominy test results obtained in different samples from a given cast, or even from a given billet of steel, are considered.

I was especially interested in the authors' comments on the induction period before transformation takes place. They appear to have taken the view that the effect of time spent in the induction period, in the intermediate temperature range, is independent of time spent in the induction period, in the pearlite range. I am not completely satisfied about that.

It seemed to me that in the case of steels such as No. 8, which was a 3% nickel steel exhibiting a single nose on the **S**-curve, there are some grounds for the view that the **S**-curve is made up of overlapping pearlite and intermediate transformations. There are likely to be great difficulties in dealing with the integration of time spent in the induction periods associated with these two overlapping transformations.

I put this emphasis on the induction period because, when a steel is being heat-treated, the main concern is to avoid transformation ; the intention is that the steel should pass through these induction periods without the time being long enough for high temperature transformation products to develop.

* *Journal of The Iron and Steel Institute*, 1948, vol. 159, June, pp. 137–144.

Mr. **D. A. Oliver** (Wm. Jessop and Sons, Ltd.) : I think we can all accept the fact that the agreement on a number of steels is remarkably good. I should like to be sure that I have understood the physical assumptions correctly. The authors state that the rate of transformation is independent of either the amount of transformation up to a given time, or of any other transformation which had already occurred. Would the authors please restate, briefly, the underlying assumptions and the procedure adopted ?

Robbed of all their complexity, if the steel is half transformed at 350° C., and then held for a period at 350° C., assuming it is held there on a kind of step-cooling curve, is the rest of the transformation at 350° C. considered as independent of its previous history ?

The authors appear to treat ' hardness ' as though it were a real physical quantity built up of additive increments. Does it mean that, when we put a diamond indenter on to steel with a fixed load, the diamond sinks in until the yield-point of the metal effects equilibrium ? Can we visualize the structure as having changing yield-points according to the amount transformed ? If so, it is easier to visualize soft material changing to hard. The diamond sinks into a soft steel until there is equilibrium. After heat-treating the same steel and repeating the experiment, broad bands in the structure may have transformed, thus increasing the yield-point, and a higher hardness will be registered. After still further heat-treatment, the chances are that the bands will have developed with still greater detail, so that it is like making indentation-tests on a piece of metal of which the microstructure looks like a piece of tartan, but with progressively more adornment. Do the authors agree that their work is consistent with this view ?

Mr. **E. H. Bucknall** (The Mond Nickel Co., Ltd.) : It is a shortcoming of the end-quench hardenability test that it does not distinguish between small degrees of transformation at high temperatures (giving soft transformation products), and larger degrees of transformation at lower temperatures (where the transformation products are harder). In their earlier work the authors showed that interruption of the end-quench provides a means of resolving this question. In this paper they take up the question of the connection between the isothermal transformation diagram of a steel and its end-quench hardenability characteristics, and show (on certain assumptions) that the hardness distribution along an end-quenched bar can be derived from isothermal data, to a reasonable approximation, for both hypo- and hypereutectoid steels.

The authors' conclusion that there is a close correlation between isothermal and continuous cooling phenomena supports those of earlier workers, such as Griffiths, Pfeil, and Allen,* who drew attention to the connection between the isothermal transformation velocity of steels in the intermediate range, and their content of bainite, when oil-quenched in a given section.

The fact that the derived diagram is for an end-quenched bar may lead some people to suppose that the authors' conclusions have little bearing on the behaviour of bars when normally quenched with total immersion since, in the Symposium on the Hardenability of Steel,† much was made of differences between the cooling curves characterizing the two sorts of quench. It is therefore pointed out that these differences are, in fact, almost completely confined to the early stages of quenching, and are practically non-existent below A_1, that is to say, in the temperature range in which transformation is likely during quenching.

It would be easy to read more into the present paper than is justified, or the authors probably intend. As illustrated in Tables V and VI, a variety of assumptions could be made in the derivation of continuous-cooling results from isothermal data, without substantial alteration of the hardness value finally computed. The authors must not, therefore, be taken to have proved that their assumptions are valid.

I think that the authors have made assumptions, not explicitly referred to in the text, which reduce the possibility of substantial error in the computed hardness. In the method of calculation used in Table IV, for instance, there seem to be several assumptions which cannot be strictly defended, namely :

That transformation always proceeds homogeneously, and not in stages which yield products with different hardnesses

That a uni-directional change of hardness always occurs as transformation proceeds

That a given amount of transformation product will make the same contribution to hardness, independent of the nature or hardness of the remainder of the steel

That, for all continuously cooled steels, transformation reaches the same stage of completeness at room temperature, irrespective of the route by which that temperature is reached, and that any contribution of residual austenite can be ignored.

Isothermal transformation studies have shown that in the pearlite range a stage of pro-eutectoid reaction precedes the final stage in both hypo- and hypereutectoid steels, and that multi-stage transformation sometimes occurs also in the intermediate range. An example is afforded by the 3% chromium, high-carbon steels studied by Lyman and Troiano.* In these steels transformation at 200 to 400° C. has a rapid first stage involving the formation of needles, which later disappear from the structure and, therefore, can hardly be regarded as having contributed to the final hardness. A rather striking example of hardness changes during two-stage transformation is afforded by the behaviour of an En 56 steel containing 13% of chromium and 0·3% of carbon ; it can transform isothermally only within the pearlite range, where transformation proceeds in two stages—carbide separation, followed by pearlite formation. At 650° C., transformation starts in 5 min., and completes itself in 30 min. If austenitized specimens of the steel are exposed in a lead bath at 650° C., and quenched to room temperature after progressive intervals of time, a room-temperature hardness curve results, which falls smoothly from 600 to 240 D.P.N. over this 25-min. period. If, on the other hand, the hardness is measured after the same time intervals, at 650° C., by means of a test applied above the M_s temperature for this steel (280° C.), the hardness is shown to increase during the first stage of transformation and to begin to fall only when the second stage gets under way, after about 15 min. The hardness tests above M_s were made by a dynamic method—a means of isothermal transformation study which has recently been used at Purdue University by Enos, Peer, and Holzworth.† This experiment reveals an instance where transformation does not proceed in a single stage, where there is not a progressive change of hardness, and where the hardening action of

* W. T. Griffiths, L. B. Pfeil, and N. P. Allen, *The Iron and Steel Institute*, 1939, *Special Report No.* 24, pp. 343–367.

† *The Iron and Steel Institute*, 1946, *Special Report No.* 36.

* T Lyman and A. R. Troiano, *Transactions of the American Institute of Mining and Metallurgical Engineers*, 1945, vol. 162, pp. 196–222 ; *Transactions of the American Society of Metals*, 1946, vol. 37, pp. 402–448.

† G. M. Enos, G. J. Peer, and J. C. Holzworth, *Metal Progress*, 1948, vol. 54, No. 1, July, p. 51.

the transformation product is apparently dependent on the hardness of the remainder of the structure.

AUTHORS' REPLY

Mr. **W. I. Pumphrey** and Dr. **F. W. Jones** wrote in reply: We thank Dr. Pfeil for his remarks. We agree that the volume of results presented in the paper is small, but we think that the results are sufficiently encouraging to make the methods used worth reporting, in the hope that it will stimulate further interest in the problem. With regard to the effect of time spent in the pearlite range on the induction period in the intermediate transformation range, we feel that the problem is likely to be exceedingly difficult to deal with by calculation, unless one or other of the following two assumptions is made:

(i) The pearlite and intermediate transformations are quite independent of one another, so that partial transformation (or induction) in the pearlite range has no effect on the commencement and rate of transformation in the intermediate range. This has been called "discontinuous transformation" in the paper.

(ii) In the pearlite and intermediate ranges the transformation is of the same type, so that after a proportion of the steel has transformed, the rate of transformation is independent of whether the previous transformation was to pearlite or bainite. This was referred to as "continuous transformation."

Where the pearlite and intermediate transformation ranges overlap, so that it is impossible to separate them, the second assumption must be made in the calculations. It is unlikely that either assumption is strictly correct; on the other hand, the results reported in the paper suggest that either assumption is unlikely to lead to serious error.

In response to Mr. Oliver's request for a re-statement of the underlying assumptions in our work, we should like to make it clear that we have assumed Scheil's criterion for the start of the transformation. As regards the procedure during the transformation, suppose that a certain amount of transformation, say 20%, has occurred during cooling to a particular temperature, say 375° C. We assume that the rate of transformation during the time spent at 375° C. on the step-cooling curve is the same as if the 20% of transformation had occurred at 375° C. If some transformation has occurred in the pearlite range it is perhaps more correct to start the calculations afresh in the intermediate range, rather than to proceed as if the transformation was of one type only, and additive throughout. However, as shown in Tables V and VI of the paper, whichever of these two procedures is adopted has very little effect on the calculated hardness.

We should not like to commit ourselves to Mr. Oliver's views on hardness. That the hardness of a piece of steel is the weighted mean of the hardnesses of its constituents appears to be the most reasonable view to take, and is consistent, qualitatively, with results on specimens of duplex structure (martensite and a softer transformation product) quenched during isothermal transformation work. We did not go more deeply into the matter.

We agree entirely with Mr. Bucknall that the similarity between the observed and calculated Jominy curves is by no means to be taken as proving the various assumptions necessary to the calculations. On the contrary, as mentioned, we feel that certain of the assumptions may not be strictly true. However, the investigation was carried out, not to determine whether or not the assumptions were exact, but in order to see whether they were near enough to obtain a rough idea of the hardenability of a steel from its **S**-curve. The fact that the assumptions are not strictly true means that the correlation between hardenability and the isothermal transformation diagram is not likely to be exact. The problem is rather similar to that of the correlation of the Jominy test with results on quenched rounds; here again, it is necessary to make certain assumptions, such as the constancy of the heat-transfer factor, which are not strictly true; hence the correlation is only rough, but it is nevertheless useful.

Discussion on the Paper—

A NOTE ON THE DETERMINATION OF MOISTURE IN PRODUCER GAS*

by J. Pearson and R. Toye

Dr. **G. W. C. Allan** (The British Coal Utilisation Research Association, Leatherhead, Surrey): During our investigations into gas-producer practice we have given the Fischer-reagent method an extended trial, and in congratulating the authors on their excellent paper, we may state that we fully endorse the method from actual experience. It should be pointed out, however, that the moisture is determined from a bulk, as distinct from a snap, sample, and that a trained analyst is needed for reliable results.

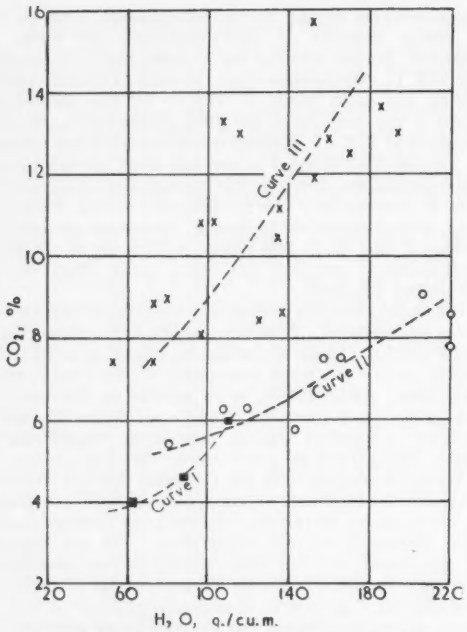
In a producer, one is trying to combine carbon with oxygen, and also with steam, to form gaseous fuels, and the effectiveness with which these blast gases are converted to useful fuel gas is a measure of the competence of the machine and its operators. The exothermic reaction of oxygen to carbon monoxide is relatively easy with normal gas coals. The endothermic carbon–steam reactions are more critical, however, and the efficiency of this conversion is a real test of the competence of the producer men. In the glass industry, the question of making gas analysis the basis of a wage incentive scheme for the men has often been mooted and has even been tried. The percentage CO_2 in the cold clean gas is the well-known rough-and-ready criterion of gas quality, but it is surely desirable in a matter such as this, where fairness is especially needed, to reinforce it with some other factor such as the efficiency of steam conversion.

We are in the process of carrying out tests for moisture in producer gas in which the Fischer-reagent method is being compared with dew-point readings, using apparatus developed by Mr. D. Flint, of B.C.U.R.A., and recently described.† So far, some interesting results have been obtained, particularly the variations possible in the moisture content, even during steady running. In the Templeborough producer, a Morgan, the moisture content was found to vary between 20% (by volume, on the hot, raw, tar-free gas) just after feeding coal to 5·6%, a figure obtained after the coal feed had been stopped for 3 min.

The authors offer the theory that a high steam content

* *Journal of The Iron and Steel Institute*, 1948, vol. 159, Aug., p. 410.

† *Journal of the Institute of Fuel*, 1948, June, p. 248.



Curve I—Coal *F*, producer *A*, fuel bed in good condition, varying load.
Curve II—Coal *B*, producer *B*, fuel bed in good condition, varying steam/air ratio.
Curve III—Gas from hot spots, fuel beds in bad condition, constant steam/air ratio.

Fig. A—Relation between CO_2 and humidity, under various conditions

in the gas consumes the carbon particles in the open-hearth furnace flame by the water-gas reaction before they can contribute to the luminosity. If this is so, then an air-atomized oil burner ought to produce a vastly more luminous flame than one using steam atomization. Is any information available on this point ?

In the oil industry attempts to apply the water-gas reaction to gasify soot and other unreactive forms of carbon have not been successful, as temperatures higher than those found in an ordinary fuel bed are needed for the reactions to proceed at a reasonable rate.

Belcher and Allen's method of moisture determination appears to be similar to a method published by Scheeben,* of Krupps, in which magnesium nitride was used instead of calcium hydride as in Belcher and Allen's method. With this 'getter' the moisture was determined by titrating for ammonia.

Ir. **J. E. de Graaf** (Koninklijke Nederlandsche Hoogovens en Staalfabrieken N.V., Ijmuiden, Holland): The authors' statement that moisture determination at the producer can do little to give information about the condition of the fuel bed which cannot be deduced from the CO_2 figures, together with blast saturation and blast temperature, is perhaps true—I am not sure—but it should certainly not be generalized to mean that humidity measurements are not required if the CO_2 is determined. It is well known that the reactivity, however defined, depends on temperature and its distribution, on the properties of the coal, on the size of the coal, and so on, and also that the rate of reduction of CO_2 and the reduction of water are different functions of these variables. This explains why a relation was found between CO_2 and humidity, and also why different relations were found for different conditions. Figure A shows that this difference can be large. It should not be concluded, therefore, that CO_2 gives sufficient indication of the humidity and that humidity measurements are not necessary.

A statement from Wesseman, quoted by the authors, might imply that below a certain degree of humidity, humidity measurements are not necessary. I disagree with that. With a certain amount of humidity the number of soot particles in the flame is decreased in the same percentage, but that decrease is less noticeable with a very thick flame than with a thin flame. In both cases it can be shown that the soot is attacked and the radiation of the flame is decreased.

I think that the chemical method of determination, developed by the authors, is a very valuable tool for investigation, but it is less suitable for routine determinations. The pressure–temperature method is not a nice method, but it has the advantage that it can be operated by any member of the team, and that has been done by us in many cases.

The real solution of the problem would be a recording or indicating instrument. Do the authors visualize such an instrument based on the principles of their methods ?

Dr. Allan inquired about the influence of steam on the radiation of an oil flame, when comparing the atomization of oil by steam and by air. We have carried out experiments of that type, and have found a slight, though significant, difference of not more than a few percent in the melting time of the charge.

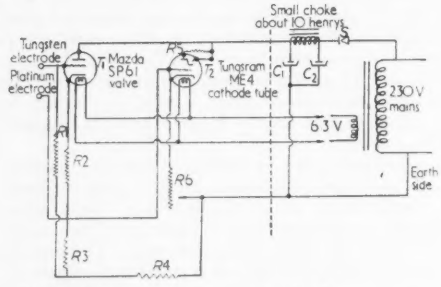
* *Brennstoff Chemie*, 1942, vol. 23, p. 120; Arrow Press Publication No. 7.

CORRESPONDENCE

Mr. **A. H. Edwards** and Mr. **A. H. Smith** (The British Coal Utilisation Research Association) wrote: In the method devised by Dr. Pearson and Mr. Toye, which was made available to B.C.U.R.A., deposition of tar in the pyridine used for dissolving the moisture is partially restrained by throttling the flow of gas; this maintains the temperature of the apparatus somewhere between the dew-point of the tar and the dew-point of the moisture. If, however, too much tar is dissolved by the pyridine, the brown end-point which appears when the solution is titrated with Karl Fischer reagent, is difficult to observe. Direct titration by Karl Fischer reagent is also not the most accurate method and an electrometric method of titration was therefore developed.

The principle of McKinney and Hall's* electrical

* C. D. McKinney and R. T. Hall, *Industrial and Engineering Chemistry* (*Analytical Edition*), 1943, vol. 15, p. 460.



R1	100,000 Ω	C_1	16 μF
R2	1200 Ω	C_2	8 μF
R3	1000 Ω	S	30 μ amp., ½-wave, selenium rectifier
R4	22,000 Ω		
R5	500,000 Ω		
R6	Variable-control resistor, 22-000 Ω		

Fig. B—Titrimeter circuit

circuit, utilizing a cathode-ray 'magic eye,' was modified to suit British valves and a 230-V. supply, in conjunction with tungsten/platinum electrodes for determining the end-point of the titration. In this circuit, shown in Fig. B, the delicate and expensive galvanometer generally used in electrometric titration apparatus is replaced by the 'magic eye' tube.

A small polarizing potential of 15 mV. is placed across the tungsten/platinum electrodes dipping in the solution to be titrated, and the charges on these are amplified by a Mazda *SP*61 vacuum tube. The amplifier is coupled to the 'magic eye,' which serves as the indicator.

The absorption technique was similar to that of Pearson and Toye, with the exception that it was found more convenient to substitute Karl Fischer reagent for pyridine in the absorption vessel. It was also necessary to couple a second absorption vessel to the absorption train, as it was found that with a gas rate of 1–1½ litres/hr., 5–10% of the moisture content of the gas passed through the first vessel. A special titration assembly and titrimeter circuit were also developed. These are shown diagrammatically in Fig. C.

Figures for the moisture content of gas from an 11-ft. Morgan producer are given in Table A. The coal supplied was a Yorkshire Doubles from the Doncaster area. The steam supplied to the producer was at 50° F. superheat, which explains the lower water content of the gas as compared with the figures reported by Pearson and Toye.

The method can also be applied to the determination of moisture in flue gases, hydrocarbon gases, and air.

AUTHORS' REPLY

Dr. **Pearson** and Mr. **Toye** replied: We thank both speakers for their valuable contributions, and are particularly pleased to learn that B.C.U.R.A. have adopted our method to determine the amount of moisture in producer gas. We congratulate them on the development of a 'magic eye' titrimeter which, when used in conjunction with the general procedure described by Bonner,* should facilitate the adoption of the Fischer method for the estimation of water in many other technical products and processes. It is mentioned in our paper that an electrometric titration would be more accurate. We have always borne in mind one important thing. At the start of this work we used the dew-point meter, and grave doubts were expressed whether we could really detect this film of moisture on account of the tar being deposited, and so we thought we ought to develop another method. We found that Belcher and Allen's suggestion of dissolving the gas in pyridine was not suitable, and so tried the Fischer method. It must be remembered that this method has to be used in an average works laboratory by the man who does the routine analysis; we do not agree that a trained analyst is required for this work, because all these titrations were done by a man who had until a few weeks previously been a shift chemist at a works. Furthermore, the sight of the apparatus for the electrometric method would frighten people away, and the average works would not bother to obtain it.

Dr. Allan mentioned the difficulty of seeing the end-point in titrating, owing to discoloration. We had no trouble in that respect. By partly throttling the tube through which the main gas stream flows, the temperature in that tube could be controlled at between the dew-point of the moisture and the dew-point of the gas: by this means a fractional separation of the moisture and the tar was effected, and the amount of gas drawn through was controlled, so that too much tar was not introduced into the liquid and there was no difficulty in deducing the end-point.

We are interested to learn of the necessity for a second absorption bottle. We have never found any moisture escaping the first bottle, and this point was specifically

Table A

MOISTURE CONTENT OF GAS FROM 11-FT. MORGAN PRODUCER

Time and Date	Moisture, g./cu. ft.	Last Ashing Time	Blast Saturation Temp., °C.	Average Coal Rate, lb./hr.	H_2O (Wet Basis), vol.%
4 p.m. 18.3.48	1·707	8.10 a.m.	58·8		7·53
5 p.m. 18.3.48	1·623	8.00 a.m.	58·8	3510	7·15
5 p.m. 19.3.48	0·729	11.10 a.m. 5.45 p.m.	59	3125	3·2
2 p.m. 4 p.m. 6 p.m. 20.3.48	1·035 0·884 0·982	8.00 a.m.	59·5 57 58·5	4370	4·57 3·9 4·33
1 p.m. 3 p.m. 7 p.m. 21.3.48	0·890 1·01 1·320	10.40 p.m.	57·5 57·0 58·0	4440	3·92 4·45 5·82
3 p.m. 4 p.m. 7 p.m. 22.3.48	1·226 1·42 1·492	10.00 a.m. 3.25 p.m.	57 52 (?) 56·5	4195	5·4 6·26 6·58
3 p.m. 6 p.m. 23.3.48	1·426 1·128	9.45 a.m.	56 56	4605	6·37 6·22

* T. G. Bonner, *Analyst*, 1946, vol. 71, p. 483.

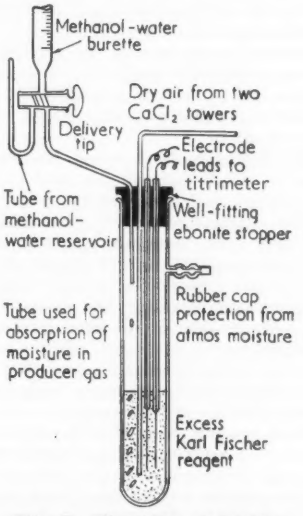

Methanol-water burette
Dry air from two $CaCl_2$ towers
Delivery tip
Electrode leads to titrimeter
Tube from methanol-water reservoir
Well-fitting ebonite stopper
Rubber cap protection from atmos moisture
Tube used for absorption of moisture in producer gas
Excess Karl Fischer reagent

Fig. C—Titration assembly

investigated, but apparently there are conditions under which this is possible, and we are grateful to Mr. Edwards and Mr. Smith for confirming the desirability of using two absorption vessels.

The question about the effect of steam and oil will be left to those who have more experience on that subject.

Ir. de Graaf does not agree that the determination of the moisture in the gas cannot give any information about the state of the fuel bed that is not revealed by the carbon dioxide content and the analysis of the coal. He himself did not actually state that definite recommendations as to any action to take could be made from moisture determinations. Until we are sure, therefore, that moisture determinations can help the producer man we should hesitate to recommend another routine control. More work will probably have to be done on that first.

We agree that a recorder would be ideal, and we should very much like to see one developed: we understand from Dr. Allan that it is intended to develop such a recorder in the future.

We are very interested in the graphs showing the relations between CO_2 and humidity and the various conditions in the producer. They certainly suggest that humidity measurements might be useful in determining optimum producer operating conditions, and we withdraw the statement in our original Note, to which Ir. de Graaf takes exception, but we reassert that further investigation is necessary before humidity determination can be recommended as a routine measurement.

Discussion on the Paper—

FATIGUE TESTS ON CRANKSHAFT STEELS* *by P. H. Frith*

Mr. **P. H. Frith** (Bristol Aeroplane Co., Ltd.) presented his paper.

Dr. **H. Sutton** (Ministry of Supply): The author and his colleagues were among the first to recognize the potentialities of nitriding steels, and their work, carried out with the help of a number of progressive steelmakers, has resulted in a factual improvement of performance, and has influenced the course of development of nitriding steels for highly stressed engine components.

The depth-hardness curves shown in Fig. 1 bring out, in a very striking manner, the possible variation in hardness alone, in a nitrided case, in the one steel with which the author has been working here. An outstanding feature is the difference between the short-period and the long-period nitriding, in respect of the influence on hardness, at different points in the case.

One outstanding point, in my view, is the tremendous benefit that the author has shown can be realized from very thin nitrided cases. A case 0·004 in. thick seems very little to which to look for the substantial improvement in fatigue performance. The work, however, has shown that a great benefit can be realized from quite a short-time nitriding operation, producing quite a thin case.

It is important to recognize that there has been a very marked change in taste among users of nitrided steels since the earliest days when nitrided steels, with rather brittle and harder cases, were used. We are now in the range of steels which are more reasonably handled after nitriding, because the case is less fragile, but in which we can yet realize tremendous benefit to the engineering properties as a result of these rather thin cases.

Practical people will be interested in the potentialities of the 10-hr. surface-hardening treatment at a modest temperature, carried out much more cheaply than many carburizing operations and with very little distortion of the work. One is encouraged to think of this as a strong competitor in the future of carburizing.

With regard to the calculation of stresses at the point of origin of fracture on broken test-pieces, we shall have to be a little careful: for a nitrided specimen, it is important to keep in mind the fact that the stress distribution is far from uniform in the specimen before we apply external stresses. Bardgett[1] has given a graphical representation of the stresses in a nitrided case, starting with compression at the surface and coming to tension, which fades away towards the middle of the bar; a compression stress, in the case itself, is balanced by a tension stress in the core. If we apply a bending stress, the curve is displaced until the whole thing may be so tilted that the surface stress becomes insignificantly lower or higher than the stress inside, and then, presumably, cracks tend to start at the surface.

On this question of improvement of the intrinsic fatigue properties by nitriding, Mailänder[2] came to the conclusion that the real fatigue properties in the surface layer were improved by the nitriding. It would be of interest to know whether Mr. Frith considers that the results he has obtained, especially on these thin cases, are in line with Mailänder's view. When one considers the great improvement given by a very thin case on a specimen with a powerful stress concentration, the effect seems too big to be attributable mainly to the case itself.

The author's results seem to me to require us to take notice of oil holes, notches, etc., but show us that, although they do produce harmful effects, those effects are greatly alleviated by nitriding.

The author's fatigue results on the 90-ton nickel–chromium–molybdenum steel are of much the same order as those of the 60-ton nitrided steel; that brings out very well the enormous advantages which can be achieved by nitriding.

Mr. **L. W. Johnson** (The Mond Nickel Co., Ltd.): I think that it will be generally agreed that the manufacture of alloy steels, especially those for aircraft purposes, has reached a very high standard, and the main need now is to show the engineer how he may make the best possible use of those steels. In the first part of the paper, the author has shown the valuable effect that nitriding has in reducing the loss in fatigue strength due to oil holes; thus, in the unnitrided condition, an oil hole causes a drop of 56% in the value for reversed bending, and 47% for torsional fatigue. Nitriding shows respective drops of only 28 and 17%. I think that a word of caution is necessary at this stage, as it is possible that this improvement, due to nitriding, may be accentuated somewhat by the 'scale effect,' *i.e.*, the proportion of the nitrided case to the core is much higher in the test-piece (especially the type which is 0·300 in. dia.) than would be so in, say, a

* *Journal of The Iron and Steel Institute*, 1948, vol. 159, August, pp. 385–409.

large crankshaft, and consequently one might not find such a big improvement for the latter. It would be interesting to know whether the author is contemplating some large-scale tests to prove, or disprove, this point. It is noted on p. 396 that tests carried out by the Motor Industry Research Association (formerly the Institution of Automobile Engineers' Research Department) indicate that there is no appreciable difference due to variation in depth of case, but perhaps the work could be extended to cover the above point.

The author mentions that, in the solid specimens without notches or oil holes, the fracture commences at, or near, the junction of the case and core, and this is advantageous because surface imperfections have less chance of initiating fatigue failure at lower values of stress. In the hollow-with-oil-hole specimen, however, failure commences at the surface, which is not quite so satisfactory. I would like to ask the author whether this is bound to be the situation in full-size components, because it means that special care will have to be taken to avoid surface damage at the oil hole due, say, to careless grinding, handling, etc.

With regard to Part II of the paper, which deals with fatigue tests of un-nitrided specimens, I imagine that whilst this investigation was primarily designed to compare two steels which are used often in the nitrided condition for crankshafts, it is really a forerunner of more data to come. The point I wish to make is that Sachs[3] and others[4] have shown that if fatigue strength is plotted against tensile strength it will be found that, for reversed bending of plain specimens, the ratio is in the region of 0·5 up to, say, 80 tons/sq. in., and then falls away somewhat, although the actual fatigue value itself still increases, and this is confirmed by the data given by the author on p. 406. If, however, notch fatigue results are plotted, there is a tendency for a maximum fatigue value to be reached at, say, 80–85 tons/sq. in., and then for a slight fall to occur with higher tensile levels, *i.e.*, the notched fatigue curve does not conform to the plain fatigue curve.

The author has taken two particular tensile values on his hollow-with-oil-hole fatigue curve, but it is not at present possible to ascertain the shape of it. I would therefore like to suggest that in subsequent work he fills in a few of the gaps, because the information would be of value in enabling designers to select the optimum tensile level for their particular requirements, bearing in mind machinability. Perhaps the author could also include some of the other types of steels, such as En 23, En 26, etc., which are used for crankshafts in the un-nitrided condition. In this connection, has the author carried out any work on the possibility of improving the fatigue strength of the oil-hole specimens by cold work at the mouth of the oil hole ?

Reference has already been made in discussing the first section to the 'scale-effect,' and it also applies in this particular section. Published work up to date has been confined mostly to medium tensile levels, and it would appear that as the size of the test-piece is increased, so the fatigue values of both plain and notched specimens fall. Hempel[5] has shown that notch sensitivity may be individual to the particular steel, and does not necessarily increase directly with the tensile strength. Thus, in comparing two steels, one with a low-carbon and medium-alloy content, having a tensile strength of 80 tons/sq. in., and the other of higher-carbon and low-alloy content, with a tensile strength of 66 tons/sq. in., the former, in spite of its higher tensile strength, had a lower notch sensitivity. Hempel also found that the notch sensitivity of both steels reached a maximum at a ratio of a/d of about 0·25, where a and d are the diameters of the transverse hole and of the test-piece, respectively. If this is so, then quite a wide field is open for further exploration, covering such aspects as the effect of a high, or low, elastic-limit/tensile-strength ratio, carbon content, the presence of tempered intermediate product, and so on.

Mr. **D. A. Oliver** (Wm. Jessop and Sons, Ltd.) : With reference to the thin casing of 0·004 in., produced with a 10-hr. treatment, the author proposes to overcome the usual problem of grinding by suggesting that we should just hone instead. That is a good solution for relatively small components, built-up as the Bristol crankshafts, but if we take an ordinary Diesel engine multi-throw crankshaft we have to be very careful how we support it in the furnace when nitriding it, and we usually avail ourselves of the depth of case to rectify small distortions which occur during the nitriding operation. Our experience has been that even after certain pre-treatments there is still the chance of serious movements which, if we cannot grind to rectify, must certainly be kept down to not more than 0·001–0·002 in. to give an error of less than 0·001 in. on the throw. I should therefore like the author to amplify somewhat, what he visualizes, because it would be most valuable to be able to avail ourselves of this curtailment in the process, with the lower sensitivity to notch fatigue.

In connection with Fig. 1, can we rightly deduce that the lowered hardness with longer times of nitriding is actually due to the surface reaction proceeding in the reverse direction ? Normally one nitrides and builds up a saturation layer ; then the continuation of the process diffuses the nitrogen inwards, and possibly a certain over-concentration of nitrogen occurs in the surface which finally causes the reaction to reverse. Is this view correct ?

In connection with Part II of the paper, were the author's steels meant to be typical, and does he normally prefer such high molybdenum contents as 0·90 and 0·98% ? In my experience, the molybdenum contents usually run rather lower than that.

Finally, I should like to draw attention to a steel of great possible interest, namely, the 3% chromium–molybdenum with 0·75% vanadium. This steel first arose in Germany as one which resisted hydrogen embrittlement under stress and temperature. It has quite remarkable properties, including a very high ratio of proof stress to maximum stress, associated with relatively high ductility. The high vanadium content of this steel may enable a greater depth of nitrided case to be obtained, even on the shortened nitriding period.

Mr. **J. Woolman** (Brown-Firth Research Laboratories, Sheffield) : Most of the speakers have referred to this apparent advantage of shorter nitriding treatment, and I have been wondering what was the theoretical justification for it. Dr. Sutton referred to the hypothetical stress distribution as a result of nitriding treatment, and showed that in the region of the boundary between the case and the core there was a zone of somewhat high tensile stress. This, with the superimposed stresses imposed during the fatigue tests would mean that, at that point, we were really stressing the material in fatigue under conditions of non-zero mean stress, the mean of the range being a tensile stress of a certain magnitude. Judging from the normal Goodman diagram we would expect, therefore, a lower resistance to fatigue than if the material were tested under the same range of stress, but with a zero mean stress. Similarly, in the compressive layer of the surface, where the mean of the stress range was compressive, we would expect a higher fatigue resistance. On the other hand, as we proceed towards the axis of the test-piece, the range of applied stress becomes less. With increased nitriding times the position of the tensile stress maximum would be nearer

to the centre and its magnitude would be increased. There are two opposing influences, therefore, which may account for the general trend in the change of fatigue stress with the period of nitriding.

I find it difficult, however, to see why we get the changes which the author reports, particularly for the tests under pure torsion fatigue, where, proceeding from no nitriding treatment, we get a substantial increase in fatigue resistance after 10 hr. treatment, and then a drop with 22 hr., and then a rise again with 72 hr. nitriding treatment. I cannot see any theoretical justification for that peculiar trend as an effect of increasing times of nitriding, and I wonder whether the author has not taken sufficient account of the errors of the experiments. I do not think that those errors lie in the technique of determining the fatigue stress, but we know that it is difficult to heat-treat a long bar, or several bars, with the great degree of uniformity which is required for intensive investigations of the kind which the author has carried out, and I doubt whether it would be possible, for example, to be sure that the tensile strengths of all the specimens he has used would be within a range of say 4 tons/sq. in., which may account for some of these discrepancies.

It would be a good check on the uniformity of the material if the author determined the Brinell or diamond hardness of the core material of the test specimens, stressed on the two sides of the fatigue limit which finally localized the fatigue strength of the samples. If he has those data, it would be useful to assess the value of the results in deciding on the theory behind the changes which he has observed.

Dr. **C. H. Desch** (Past-President, who occupied the chair), said : As a member of the Committee for which this work was done, I would add my testimony to the extremely careful work which the author has carried out. It involved a very large number of tests, and the results can be taken as authoritative. They are a very important contribution to the subject of fatigue. I am sure that you will wish to thank the author for presenting this most valuable paper.

CORRESPONDENCE

Mr. **W. E. Bardgett** (The United Steel Companies, Ltd.) wrote : In Part I, p. 395, the author quotes a figure of 8·8% increase in fatigue strength due partly to fracture not being initiated by surface irregularities, and states that for the steel in question, this higher fatigue limit was considered to be that for a chromium–molybdenum steel heat-treated to a maximum tensile strength of 60 tons/sq. in., having a perfect surface and tested in a vacuum. It would appear that the author has overlooked the fact that failures take place at a position where the stress is greater than the applied stress at this position, and at a point where tensile stresses are probably at a maximum. These tensile stresses are likely to be of a fairly high order, and the figure of 8·8% increase is probably appreciably less than the figure would be if the tensile stress at the position of failure were taken into consideration.

The author states that it was very unlikely that his results on nitrided specimens were affected to any appreciable extent by inclusions, owing to the consistency in the distance from the outside of the test-piece to where the fracture commenced. In view of the fact that the tensile stress below the case reaches a maximum at the same position relative to the whole surface, it is not to be expected that the depth of the origin will be greatly affected by inclusions, since it is obvious that fracture will tend to take place where the tensile stress is at a maximum, and the stress gradient, from the position of the origin of fracture to the surface and centre, is fairly steep. This applies particularly to specimens tested under uniform bending conditions. The influence of inclusions is much more readily revealed in cantilever tests, in which failure sometimes occurs at appreciable distances from the position of maximum applied stress, at a position of lower stress. This point is clearly brought out by the following results, which were obtained on a 3% chromium–molybdenum steel heat-treated to 68·6 tons/sq. in. maximum stress, specimens being taken transversely from 8-in. square billets :

Range of stress due to applied maximum bending moment, tons/sq. in	Range of stress due to bending moment at fracture, tons/sq. in.	Cycles of stress, 10^5
±28·0	±19·3	2·868(B)
±27·5	±20·0	7·908(B)
±27·25	±27·1	4·550(B)
±27·0	..	12·960(UB)
±26·75	..	12·247(UB)

(B) = Broken. (UB) = Unbroken.

On the basis of maximum applied bending moment, the limiting fatigue stress for this material is ±27·0 tons/sq. in. If, however, the fatigue limit is based on the lowest stress required to produce fracture, the figure would be less than 19·3 tons/sq. in. on the basis of this limited number of specimens. It is appreciated that this is rather an extreme case, in which transverse specimens are taken from an 8-in. square billet, and that this effect will be less in material of smaller cross-sectional area which has received a greater amount of reduction. It should be mentioned that the steel was relatively clean.

We have carried out only a limited number of microscopical examinations of fractured specimens, but the results indicate that inclusions, in certain cases, definitely do play a part, and it is more than likely that they will play a part in all cases, but to different extents, depending mainly on the amount of reduction of the material and on the direction in which the specimen is taken.

The author states that it appeared that the best nitriding treatment for solid specimens was one which produced sufficient surface compressive stress in the nitrided case, and sufficient depth of nitrided case to transfer the commencement of the fatigue fracture from the surface to the vicinity of the junction between the case and the core, with a minimum tensile stress in the core. This suggests that the degree of nitriding should be just sufficient to transfer the commencement of fracture from the surface to the vicinity of the junction between the case and the core. For specimens of the type under consideration, and for most components, this would hardly appear to be so, since there is, in general, a progressive increase in fatigue strength with increase in nitriding, after having exceeded this particular case depth, in spite of the fact that the tensile stresses are increasing. Rather does it appear to be one of considering whether the benefit obtained by increased nitriding time, beyond that which is just necessary to cause failure to occur in the vicinity of the junction between the case and the core, is justified by the additional strength obtained.

Further, it is not clear why the author should conclude that the best nitriding treatment for the type B specimen was one which produced the maximum surface hardness, unless the author is of the opinion that surface hardness was the criterion for judging fatigue strength, and that compressive stresses could be ignored. The writer does not think that the answer can be simplified in this way, considering that it is bound up with compressive stresses.

The relative dependence of the increase in fatigue limit, due to nitriding, on increase in hardness or compressive stresses, is open to conjecture, and it would seem well worth while to carry out tests on all nitrided specimens

in order to clear up this point, such specimens having the high hardness of a nitrided case, but freedom from compressive stresses.

The author may be interested to know that in tensile tests carried out in the writer's department, figures were obtained for modulus of elasticity of all nitrided specimens. The tests were carried out on 0·030-in. thick strip of 3% chromium–molybdenum steel nitrided throughout its thickness. The material gave a figure of 300 V.P.N. before nitriding and 800 V.P.N. on the surface after nitriding, and 858 V.P.N. at the centre. Before nitriding, the modulus of elasticity was 12,800 tons/sq. in. and after nitriding 13,500 tons/sq. in.

The author has clearly shown the marked saving in nitriding time which may be effected, without appreciable loss in fatigue strength, in the absence of stress concentration, and that a similar saving may be effected with oil-hole sections, with some slight advantage in fatigue strength. In this connection, it is of interest to consider data obtained in the writer's department on 3% chromium–molybdenum–vanadium steel to specification D.T.D. 551, heat-treated to a maximum stress of 94·9 tons/sq. in. Rotary uniform-bending-moment fatigue tests were made on three types of 0·5-in. dia. test-piece having fillet radii of 3 in., $\frac{1}{16}$ in., and 0 in. Four sets of fatigue test specimens of each type were prepared. The first set was tested un-nitrided, the second nitrided for 24 hr. at 500° C., the third for 48 hr. at 500° C., and the fourth for 96 hr. at 500° C. The nominal case depths for the three periods of nitriding were 0·010 in., 0·015 in., and 0·020 in., respectively.

The results of these tests are summarized graphically in Fig. A, together with results given by the author for solid and hollow-with-oil-hole specimens tested under conditions of bending stress. The difference in the fatigue results for the solid specimen given by the author, and those given by the writer for solid specimens is accounted for by the difference in tensile strength of the two steels. The forms of the two curves for this type of specimen are fairly similar and do not call for any special comment. In the case of the hollow-with-oil-hole specimen, however, the form of the curve is markedly different in characteristics from those of the writer's results for specimens having stress concentrations corresponding to $\frac{1}{16}$-in. and 0-in. fillet radii. There does not appear to be any obvious reason for this difference, in considering the different forms of stress raisers, and a closer examination of the problem would require to be made in order to find an answer, but the important point which these results reveal is that the result which the author found for his hollow-with-oil-hole specimen, in the respect that the time of nitriding could be reduced from 72 to 10 hr. without loss in fatigue strength, may not be applicable to parts subjected to fatigue stresses which have stress concentrations differing in character from those of a hollow-with-oil-hole specimen.

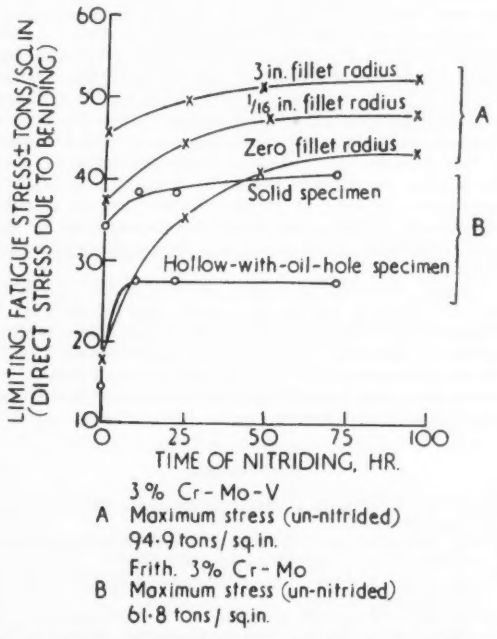


Fig. A—Comparison of the results of rotary uniform-bending-moment fatigue tests on un-nitrided specimens

In the case of the writer's results, a continuous and marked progressive increase in fatigue strength occurs with increase in nitriding time up to 50 hr. A further increase takes place on prolonging the nitriding time to 96 hr., but this increase is of a small order compared with that obtained by increase in the nitriding time for a similar period within the range up to 50 hr.

AUTHOR'S REPLY

Mr. **Frith** (in reply) : I would like to thank Dr. Sutton and Mr. Bardgett for drawing attention to the calculation of the stress where the fracture commenced. These results do not affect the final conclusions of the paper, but were considered to be a sideline worthy of insertion. When the stress was calculated, the compressive stress in the case, and the tensile stress in the core, were not taken into account because, so far, no reliable figures for these stresses with various depth-hardness curves have been given. There are many diagrams published, but as a rule numerical values are not stated and, therefore, it was decided, in view of the lack of accurate data on the subject, to take into account in the paper, only the applied stress. When these data are available, there are sufficient figures given in the paper to enable further calculations to be made. I know that some investigators consider that the tensile stress in the core of nitrided test-pieces can be quite considerable at certain positions, but if this is so, then I would expect nitriding to reduce the fatigue limit of steels under push-pull loading, where the fracture can commence at any position across the test-piece. From published data, it does not appear that this is so for test-pieces approximately 0·600 in. dia. With regard to Dr. Sutton's second point, I do think that the real fatigue properties of the surface layer are improved by nitriding. However, as Dr. Sutton states, the improvement given by a very thin case on specimens with a powerful stress concentration seems too big to be attributable solely to the case itself.

Size effect, questioned by Mr. Johnson, was referred to, in the paper, in relation to solid specimens 0·600 in. dia. As regards the hollow test-pieces with an oil hole, it was considered that if the fatigue properties of a 0·600-in. dia. test-piece were not decreased by reducing the nitriding time from 72 hr. to 10 hr., then the fatigue properties of a crankshaft at an oil-hole section would most likely not be decreased. It was decided not to carry out fatigue tests on specimens with a diameter larger than 0·600 in., before applying these fatigue results to the manufacture of the Bristol crankshaft, but to carry out overload tests on crankshafts under engine-running conditions. These were successfully carried out, and the shorter nitriding period has now been in production for a number of years, with perfectly satisfactory results.

The fracture of the nitrided hollow-with-oil-hole test-pieces 0·600 in. dia. commenced at the surface of the oil hole, and I think it is highly probable that the same type of failure would occur on a crankshaft.

I am very grateful to Mr. Johnson for drawing my attention to the work of Sachs, and for showing that the fatigue results on solid test-pieces, given in Part II of my paper, entirely agree with this earlier work. The results obtained by Sachs on notched specimens are very interesting, but I cannot comment on these as we have not sufficient data.

With regard to Mr. Johnson's last question, we have not carried out any tests on the effect of cold work on the fatigue properties of oil-hole test-pieces, because we consider that nitriding is a far better production method of ensuring uniformity of oil-hole sections on aero engine crankshafts than cold working of the surface.

In reply to Mr. Oliver, the fatigue tests were carried out in connection with the built-up Bristol crankshaft, and for a number of years we have finished the shafts by honing, after the short-time nitriding. Whether this would be satisfactory for the larger Diesel crankshafts I am not in a position to state. We have found, however, that the shorter nitriding treatment reduces the amount of distortion of the Bristol crankshaft during the nitriding period, and no doubt would do so for the larger Diesel crankshafts, but whether grinding could be completely eliminated on these larger shafts by shorter nitriding times could only be determined on actual crankshafts.

As regards the lower surface hardness which was obtained with the longer nitriding periods, I think that this was due to the formation of Fe_4N. We have detected this by X-ray means, in these steels, after the 72-hr. nitriding period, and it is our opinion, at the present time, that when this constituent starts to form, the surface hardness is decreased.

The steels chosen for Part II of the paper were meant to be typical steels to specifications D.T.D. 228 and 551. The molybdenum content stated in the specifications is 0·9–1·5% and 0·7–1·2%, whilst the molybdenum contents of the steels tested were 0·90% and 0·98%, respectively.

The 3% chromium–molybdenum steel with 0·75% vanadium, mentioned by Mr. Oliver, is certainly very interesting, and if, in the future, we decide to extend our crankshaft research, I will certainly consider including this steel.

In reply to Mr. Woolman, I agree that there does not appear to be any theoretical justification for the higher fatigue limit of solid test-pieces after nitriding for 10 hr. than after nitriding for 22 hr. In the first place, I put this down to experimental errors during the progress of the tests (see p. 395), but after completing the tests on the nitrided and ground specimens, I thought that it might be connected with the higher surface hardness, or with the distribution of the compressive and tensile stresses through the specimens (*see* p. 397).

As regards the uniformity of heat-treatment, this was checked as described on pp. 406 and 407, and each test-bar was hardness tested on at least two positions before machining. The test-bars were placed in a jig, in the furnace, to ensure uniform heating, and it was found to be possible to keep the Brinell hardness number of the 1·0-in. dia. test-bars constant. With the 3·5-in. dia. bars, it was not possible to keep all the test-sections cut from the bars to a constant Brinell, and the sections were passed for machining if the Brinell hardness number was between 418 and 402 (*i.e.*, plus nil, minus 4% on the desired value of 418).

In reply to Mr. Bardgett, I agree that for solid test-pieces the fatigue limit increased as the nitriding time was increased from 10 to 72 hr. However, by nitriding 0·600-in. dia. test-pieces for 10 hr. instead of for 72 hr., the fatigue limit was only reduced approximately 6·0%, whilst it was calculated that the reduction in the fatigue limit for a crankshaft approximately 3·0 in. dia., in the absence of stress concentration, would be less than 1·0% (*see* p. 396). Therefore, from a fatigue point of view, it did not appear necessary to increase the nitriding time for crankshafts, in the absence of stress concentration, above the value which produced sufficient surface compressive stress, and sufficient depth of nitrided case, to transfer the commencement of the fatigue fracture from the surface to the vicinity of the junction between the case and the core, so that surface irregularities are not so detrimental. Another disadvantage of increasing the nitriding time above this value was that the distortion during nitriding would most likely be increased, which would mean that grinding, and not honing, would have to be used for finishing the crankshaft.

As regards the hollow-with-oil-hole test-pieces, the statement that the best nitriding treatment was the one which produced the maximum surface hardness was based on the test results obtained in the paper. These tests showed that by increasing the surface hardness the fatigue limit of the hollow-with-oil-hole test-pieces was increased.

I would like to thank Mr. Bardgett for the modulus of elasticity values given for a nitrided case, which show that nitriding has no appreciable effect on the modulus of elasticity.

The fatigue results given on fillet type test-pieces are most interesting and, as stated by Mr. Bardgett, the results obtained on the 3·0-in. fillet specimens are similar, when allowance is made for the different maximum tensile strength, to those obtained on the 0·600-in. dia. solid test-pieces in this present paper. It was not stated where the fracture commenced for the 3·0-in., $\frac{1}{16}$-in., and zero fillet test-pieces, but I assume that for the 3·0-in. fillet test-pieces, at least, that the fracture commenced below the surface in the vicinity of the junction between the case and the core. As the curves given in Fig. A for the nitrided $\frac{1}{16}$-in., and zero fillet test-pieces are similar to the curve for the nitrided 3·0-in. fillet test-pieces, I think it is highly probable that the fracture of all the nitrided fillet test-pieces commenced below the surface. Therefore, as the fracture of the hollow-with-oil-hole test-pieces commenced on the surface of the test-pieces, it may be that the differences in the type of curves obtained for the nitrided hollow-with-oil-hole, and fillet test-pieces, may be due to the different position for the commencement of the fracture.

I agree with Mr. Bardgett that the results given for nitrided oil-hole test-pieces cannot yet be applied to components with other forms of stress concentration. However, generally speaking, the most serious form of stress concentration on crankshafts are oil holes, and that is why this form of stress concentration was chosen for this present research.

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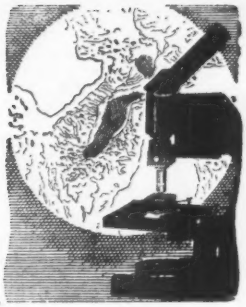
5. M. Hempel: *Archiv für das Eisenhüttenwesen*, 1938–39, vol. 12, Jan., pp. 433–444.

B. I. S. R. A.

BRITISH IRON AND STEEL RESEARCH ASSOCIATION



The Mechanism of Freezing of Horizontal Steel Castings

Submitted by the Melting and Metallurgical Committee

SYNOPSIS

A detailed metallurgical study of fifteen experimental carbon-steel castings has been made to ascertain the influence of casting temperature upon the mechanism of solidification and, therefore, upon the structure and physical properties of steel castings. Fourteen of the castings were 4 in. square, 18 in. long, and were cast horizontally, with varied degrees of superheat up to 100° C., to explore the effect of casting temperature with varying carbon contents within the range 0·12–0·54%. Another casting of the same dimensions was turned upside down before the internal solidification was completed.

It is shown that low casting temperature favours random orientation of the crystal structure, whether this be of the dendritic or of the nuclear type, and high casting temperature favours columnar crystal growth. Over a wide range of casting temperature columnar dendritic crystallization predominates throughout the upper halves of the castings. Crystallization in the lower halves of the castings appears to be far more nucleated and finer in structure. For the higher casting temperatures there is some evidence of initial columnar dendritic growth from the lower casting face, but further within the castings randomly oriented dendrites occur. At the lower casting temperatures a fine nuclear crystallization takes place from the lower casting face, and at a greater depth within the castings randomly oriented dendrites occur. The lines of demarcation between these various zones are well defined, and are often associated with significant differences in chemical composition. Similar results were obtained for the castings having a carbon content below and slightly above the peritectic limit of the δ-iron region of the phase diagram. The columnar dendritic zones are slightly harder and of higher strength than the other zones, thus conforming with the observed higher contents of carbon, sulphur, and phosphorus in these zones.

There appears to be a strong gravitational influence operating during the process of solidification, and this influence is well confirmed by a complete reversal of the structure of the casting which was inverted before solidification was complete.

Introduction

THE inception of the work was provoked by earlier published work* by one member of the Committee, and it was decided that the Committee should extend this work to obtain further information on the mechanism of freezing of steel in sand moulds. The dimensions of the blocks cast were chosen to give the blocks a simple geometrical form, and they were fed from a whirl-gate head to ensure uniform feeding conditions and a reasonable degree of soundness.

The broad objective of this enquiry was to determine the effect of casting conditions upon the variations in structure, chemical composition, and mechanical properties, at different parts of steel castings. Segregation occurs during the liquid-to-solid phase transformation, so that it was felt that a systematic control and study of the various external factors, which might have a bearing upon the internal mechanism during this phase change, would be profitable.

The investigations were restricted to a study of the effect of temperature of casting on plain carbon steels over the range of 0·12 to 0·54% carbon content. All the castings were rectangular in shape, 4 in. square and 18 in. long, and were cast horizontally. A section of the casting and head is shown in Fig. 1. The moulds were of dry sand, as used in the works in which the castings were made, except the 0·12% carbon-steel blocks, which were cast in cement-bonded sand moulds of the Randupson type. The moulds were made in standard moulding boxes which were placed on the floor of the foundry, and a minimum thickness of moulding material of 2 in. was present on all sides

*B. Gray, *Journal of The Iron and Steel Institute*, 1944, vol. 150, No. II, pp. 5P–17P.

The manuscript, a Report of the Melting and Metallurgical Committee of the Steel Castings Division of the British Iron and Steel Research Association, was received 29th December, 1948.

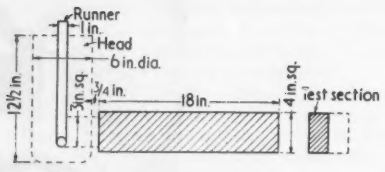


Fig. 1—Section showing dimensions of castings and their feeder heads

of the castings. The type of furnace used for the melting of the steel also varied with the different works which made the castings ; in fact, acid electric, acid and basic high-frequency, and acid side blown converter furnaces were employed. However, since the prime objective of each section of the work was to study the effect of casting temperature, and since the various casting temperatures were obtained from the same furnace of a particular works for a specified steel quality, no complicating significance need be attached to the varying steelmaking conditions.

The work was commenced by the Metallurgical (Steel Castings) Sub-Committee E of the Steel Castings Research Committee, which was a Joint Committee of The Iron and Steel Institute and the Iron and Steel Industrial Research Council. The constitution of the Sub-Committee was as follows :

Mr. W. J. Dawson (Chairman)
Mr. F. Cousans
Mr. H. Evans
Mr. B. Gray
Mr. G. T. Hampton
Mr. J. F. B. Jackson
Mr. R. Lamb (Secretary)
Mr. T. R. Middleton
Dr. W. C. Newell
Dr. L. Northcott
Mr. H. T. Protheroe

On the formation of the Steel Castings Division Panel, of the British Iron and Steel Research Association in January 1946, this work was taken over by its Melting and Metallurgical Committee, the constitution of which was as follows :

Mr. F. Cousans (Chairman)
Mr. H. Evans
Mr. B. Gray
Dr. E. Gregory
Dr. R. Hunter
Mr. J. F. B. Jackson
Mr. R. Lamb
Dr. L. Northcott
Mr. H. T. Protheroe

The necessary secretarial services were provided by Mr. R. W. Berry of the Research Association staff.

It will be seen that the new Committee has substantially the same constitution as the earlier Sub-Committee E, and this has been most beneficial for the continuity and progress of the work for this Report. The Committee wishes to acknowledge its great appreciation of the value of Mr. W. J. Dawson's initial guidance upon this work, and to express its deep regret that, because of ill-health, Mr. Dawson has been unable to continue his active participation in it. Dr. Newell withdrew from the work on his resignation from his position with the Brown-Firth Research Laboratories, but, since his subsequent appointment as Head of the Steel Castings Division of the Research Association, he has been enabled not only to continue his active support of the work, but has also been responsible for the issue of this Report.

The Committee wishes to acknowledge the support and assistance of the directors and staff of the firms with whom they are associated, and of the staff of the British Iron and Steel Research Association.

EXAMINATION OF CASTINGS

This section is a detailed statement of the examination of the castings, together with diagrams, photomicrographs, sulphur prints, and tables of results. The section has been divided into five groups, a discussion of the results following each group.

A summary of the five groups is as follows :

Group	Symbols of Castings	Melting Furnace	Carbon, %
(a)	*A*,*B*	Acid Electric	0·23 0·38
(b)	*C*, *D*, *E*, *F*	Acid H.F.	0·28
(c)	*G*, *H*, *I*, *J*	Basic H.F.	0·15
(d)	*K*, *L*, *M*, *N*	Acid Converter	0·54
(e)	*O*	Acid Electric	0·23

Group	Casting-Temp. Range, °C.	Made by	Examined by
(a)	...	B. Gray	H. Evans
(b)	1645–1495	W. J. Dawson	L. Northcott
(c)	1640–1535	J. F. B. Jackson	H. Evans
(d)	1580–1485	F. Cousans	L. Northcott
(e)	...	B. Gray	H. Evans

(a) PRELIMINARY CASTINGS *A* AND *B*

Experimental Details

Castings *A* and *B* were two of the castings made by Mr. Basil Gray at the English Steel Corporation, Ltd., in connection with his investigation into the metallurgical merits of the whirl-gate head. Mr. Gray prepared the vertical longitudinal sections of the two castings, which were cast from two melts from an acid-electric furnace to the following composition, final deoxidation in the ladle being made with 0·02 and 0·09% of aluminium respectively :

Cast No.	Casting Symbol	C, %	Si, %	Mn, %	S, %	P, %
12642N	*A*	0·23	0·30	0·64	0·030	0·040
13049N	*B*	0·38	0·38	0·64	0·033	0·042

Both castings were cast horizontally and were fed from one end by a whirl-gate head (*see* Fig. 1). Although casting *A* had been cut on the central axis to give a piece $1\frac{7}{8}$ in. thick by 4 in. deep and 18 in. long, casting *B* had not been cut squarely, and the thickness was 2 in. at the lower cast surface and $2\frac{1}{4}$ in. at the upper surface. The sulphur prints taken by Mr. Gray from the two sections of the castings are shown in Fig. 5. A point to be remembered when considering the structure and properties of these two castings is that casting *A* was examined in the as-cast condition, whereas casting *B* had been

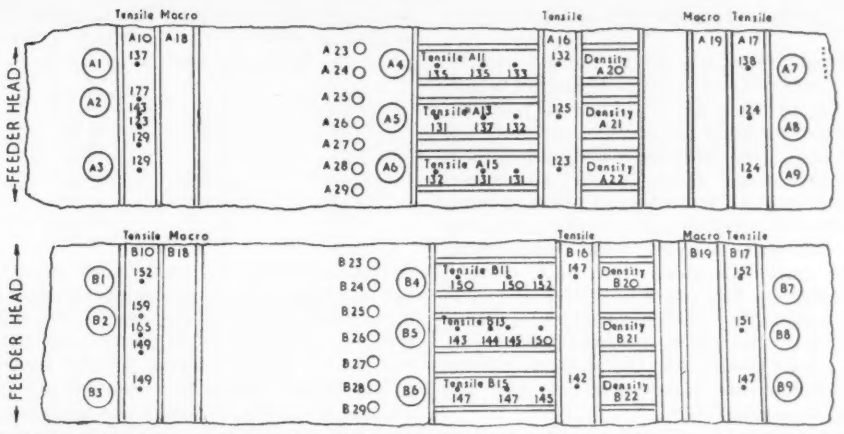


Fig. 2—Brinell hardness values and position of test-pieces (Top) Casting *A* ; (Bottom) Casting *B*

normalized before examination. Throughout this Report the test-pieces were taken as close as possible to the axial surfaces.

Results of Metallurgical Examination

The sections of the castings were examined in detail by Mr. H. Evans, and Fig. 2 is a plan to all the tests and analyses which were undertaken.

A survey of the hardness variations across the sections was made by taking a number of Brinell hardness determinations (using a 10-mm. ball and a 3000-kg. load) along the lengths of the blanks cut for

A18		*A16*		*A19*
153.		153.		166.
.155		.151		.158
159.		149.		158.
.155		.150		.144
155.		147.		146.
.150		.143		.152
159.		149.		148.
.156		.148		.151
156.		147.		146.
.149	Upper	.152	Zone	.146
151.		149.		147.
.154		.146		.147
155.		148.		149.
.154		.150		.147
155.		147.		148.
.175		.154		.150
228.		154.		166.
.184		.152		.142
155.		147.		140.
.146		.139		.140
148.		139.		140.
.143		.143		.139
143.		139.		144.
.138		.139		.141
139.		136.		143.
.140		.139		.138
147.		137.		138.
.144	Lower	.140	Zone	.143
143.		138.		142.
.144		.141		.146
145.		140.		146.
.132		.143		.142
127.		146.		143.
.140		.144		.146
151.		142.		147.
.156		.151		.148
159.		151.		154.
.154		.158		.–
144.				
Near Feeder		**Near Middle of Length**		**Near End**

Fig. 3—Diamond pyramid hardness surveys on slices from casting *A*

B18		*B16*		*B19*
177.		165.		165.
.169		.167		.172
165.		167.		170.
.167		.167		.171
167.		167.		168.
.166		.171		.167
167.		169.		168.
.165		.165		.164
163.		170.		165.
.164	Upper	.172	Zone	.168
165.		166.		161.
.165		.165		.163
167.		161.		165.
.168		.168		.161
165.		168.		161.
.199		.172		.165
175.		172.		169.
.194		.169		.189
200.		168.		171.
.188		.159		.171
168.		159.		165.
.168		.159		.165
167.		159.		162.
.164		.159		162.
161.		163.		161.
.162		.167		.165
165.		156.		170.
.166	Lower	.158	Zone	.159
168.		163.		159.
.160		.157		.160
150.		161.		165.
.157		.163		.163
150.		163.		159.
.163		.164		.161
167.		164.		166.
.170		.165		.167
169.		165.		167.
.171		.169		.160
164.		162.		159.
Near Feeder		**Near Middle of Length**		**Near End**

Fig. 4—Diamond pyramid hardness surveys on slices from casting *B*

tensile tests. The Brinell figures obtained are inserted in Fig. 2.

Diamond pyramid hardness determinations (HD/30) were made at intervals of 0·1 in. along the length of three slices cut from each casting at positions near the feeder head, near the middle, and near the far end. The respective symbols, indicated in Fig. 2, for these slices are *A* and *B* 18, 16, and 19 respectively. A full plan of all the diamond pyramid hardness figures thus obtained is shown in Figs. 3 and 4.

Complete chemical analyses were made from nine suitably spaced positions from each casting, and are indicated by the symbols *A* and *B* 1–9 in Fig. 2. The samples for analysis were obtained by drilling with a $\frac{5}{8}$-in. dia. drill to a depth of about $\frac{1}{2}$ in. The analyses were made for the carbon, silicon, manganese, sulphur and phosphorus contents, and the results are shown in Table I.

In addition, chemical analyses for carbon content were made on samples from a further seven positions in a line running across the middle of the castings, and are indicated by the symbols *A* and *B* 23–29 in Fig. 2. These positions were equally spaced across the depth of the casting, and the samples were obtained by drilling with a $\frac{1}{4}$-in. dia. drill to a depth of about $\frac{1}{2}$ in.; the figures obtained were as follows:

Position in Casting *A*	C, %	Position in Casting *B*	C, %
A 23	0·25	*B* 23	0·35
A 24	0·24	*B* 24	0·35
A 25	0·24	*B* 25	0·37
A 26	0·23	*B* 26	0·42
A 27	0·22	*B* 27	0·35
A 28	0·19	*B* 28	0·37
A 29	0·23	*B* 29	0·36

The yield point, ultimate tensile strength, percentage of elongation, and percentage of reduction in area were determined on test-pieces having a diameter of 0·252 in. and a gauge length of 0·89 in. Three such test-pieces were machined parallel to the direction in which the castings had been fed (*see A* and *B* 11, 13, and 15 in Fig. 2), and three were taken at right-angles to the direction in which the castings had been fed (*see A* and *B* 10, 16 and 17 in Fig. 2). The results obtained from these tests are given in Table II.

Determinations of density were made at three positions across the depth of each of the castings,

Table I

CHEMICAL ANALYSES ACROSS SECTIONS OF CASTINGS *A* AND *B*

Position in Casting			C, %	Si, %	Mn, %	S, %	P, %
CASTING *A*							
Near Feeder Head:	Upper Zone	*A*1	0·24 0·23	0·32	0·60	0·036	0·049
	Segregate	*A*2	0·26 0·27	0·33	0·62	0·043	0·059
	Lower Zone	*A*3	0·23 0·23	0·33	0·600	0·029	0·043
Near Middle:	Upper Zone	*A*4	0·26 0·25	0·31	0·62	0·033	0·046
	Middle	*A*5	0·22 0·23	0·31	0·60	0·028	0·043
	Lower Zone	*A*6	0·22 0·23	0·30	0·61	0·029	0·043
Near End:	Upper Zone	*A*7	0·24 0·25	0·31	0·61	0·034	0·048
	Middle	*A*8	0·25 0·26	0·31	0·59	0·031	0·042
	Lower Zone	*A*9	0·22 0·23	0·30	0·59	0·029	0·042
CASTING *B*							
Near Feeder Head:	Upper Zone	*B*1	0·36 0·36	0·41	0·68	0·032	0·040
	Segregate	*B*2	0·41 0·42	0·43	0·76	0·045	0·049
	Lower Zone	*B*3	0·35 0·35	0·35	0·69	0·034	0·039
Near Middle:	Upper Zone	*B*4	0·39 0·39	0·38	0·71	0·031	0·038
	Middle	*B*5	0·36 0·35	0·41	0·69	0·034	0·036
	Lower Zone	*B*6	0·36 0·36	0·40	0·69	0·027	0·039
Near End:	Upper Zone	*B*7	0·34 0·35	0·39	0·71	0·032	0·039
	Middle	*B*8	0·36 0·35	0·36	0·71	0·031	0·039
	Lower Zone	*B*9	0·34 0·36	0·37	0·69	0·031	0·036

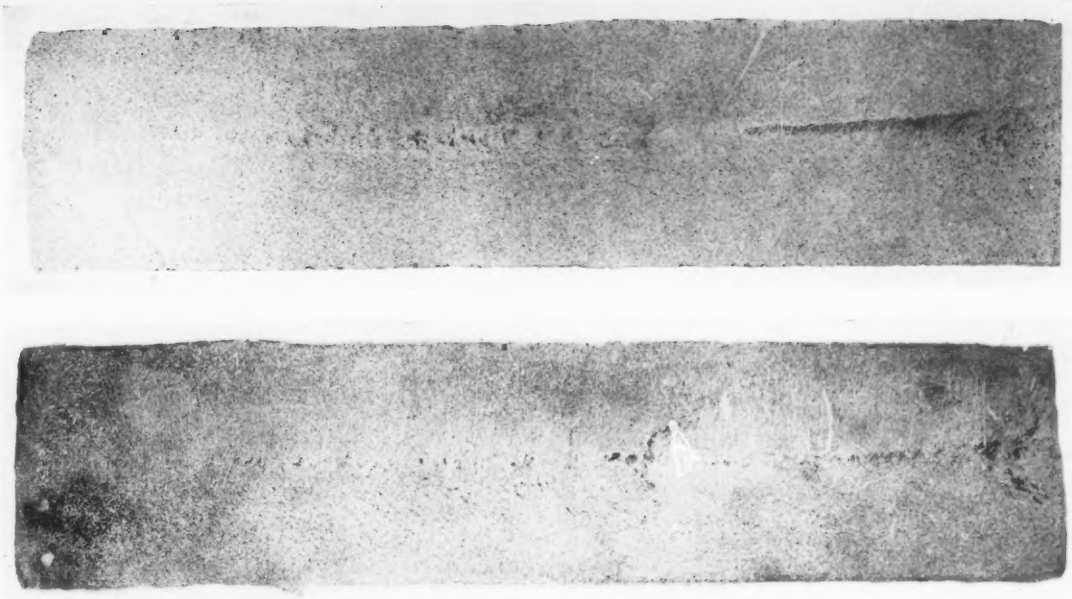
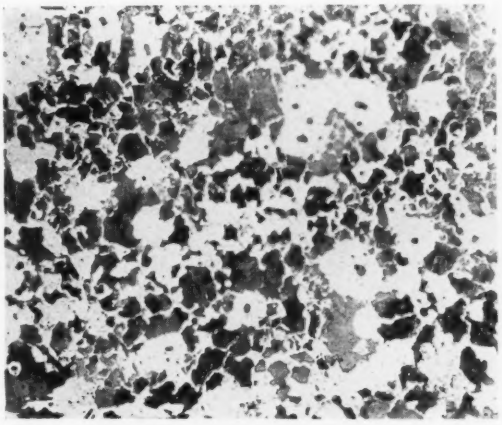


Fig. 5—Sulphur prints of casting A (top) and casting B (bottom)

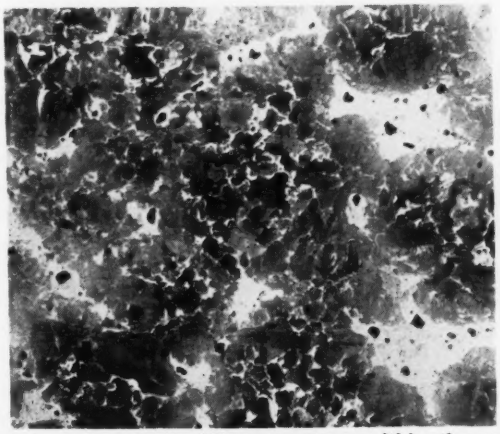
[a]

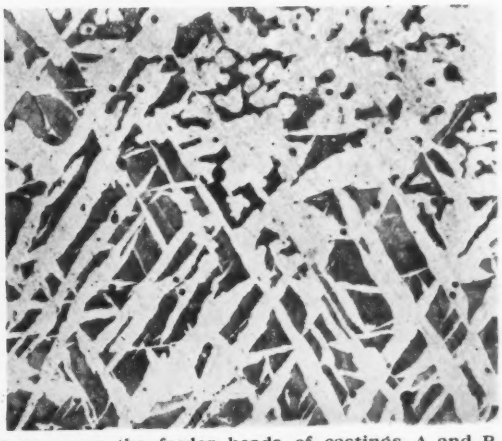


[b]

Fig. 6—(a and b)—Typical microstructures of the upper zones in castings A and B respectively. The structures of the lower zones were similar × 200

[c]

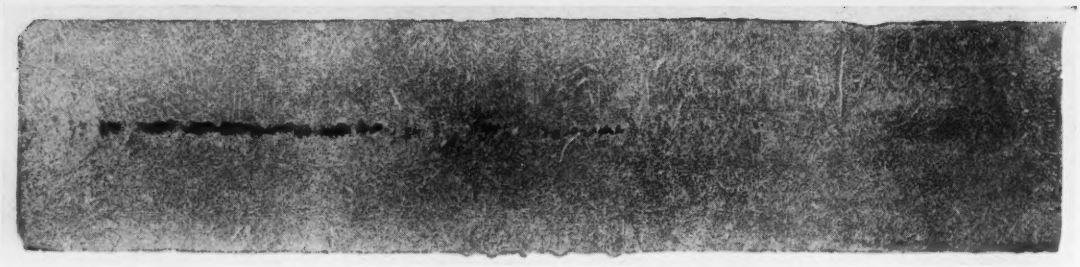




[d]

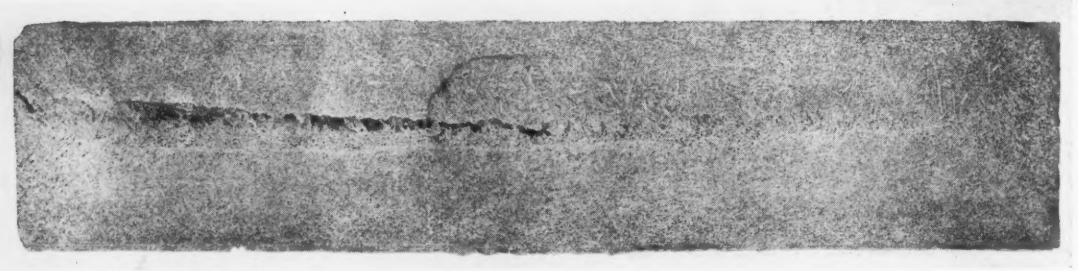
Fig. 6 (c and d)—Microstructures within the segregates near the feeder heads of castings A and B respectively × 200

Feeder End



Casting *C*

Casting *D*



Casting *E*

Casting *F*

Fig. 7—Sulphur prints of castings C, D, E, and F

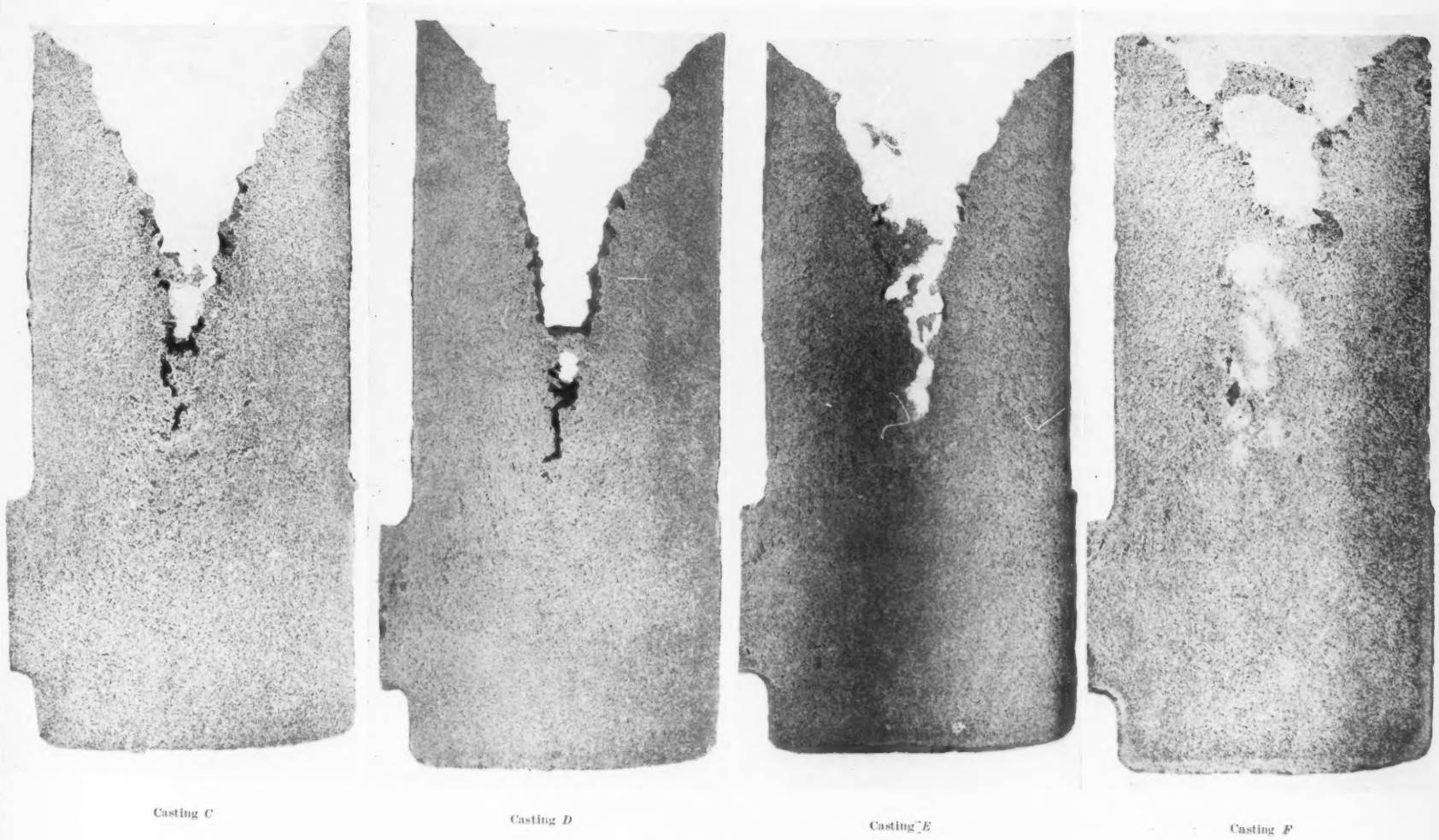
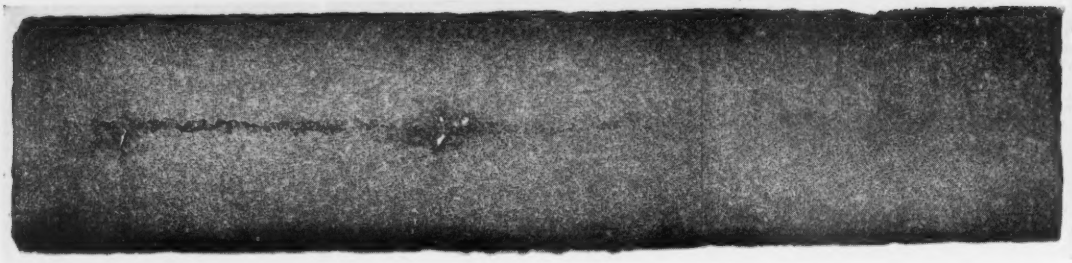
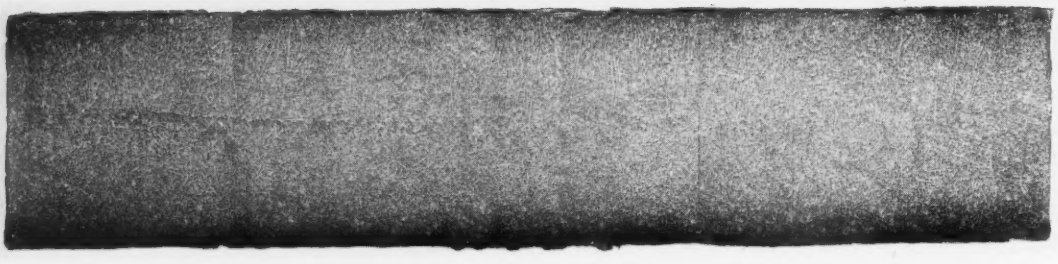


Fig. 8—Sections of feeder heads of castings C, D, E, and F

Feeder End

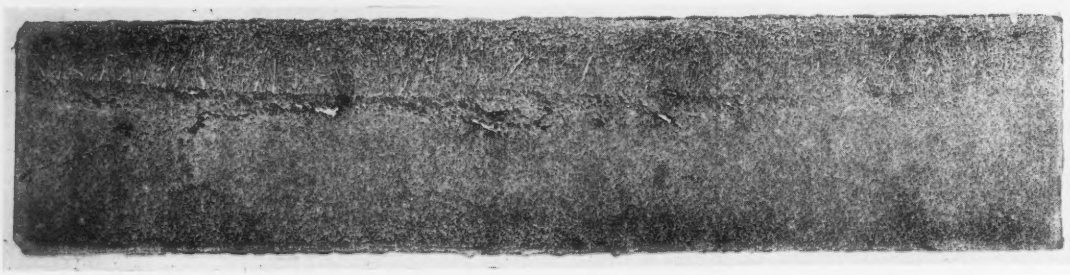


Casting *C*



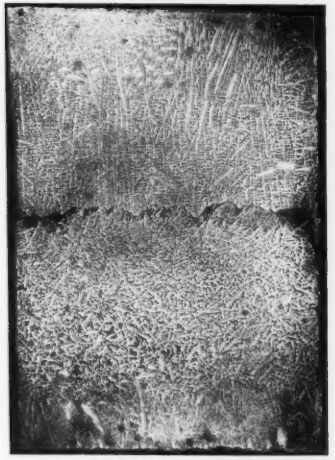
Casting *D*

Casting *E*

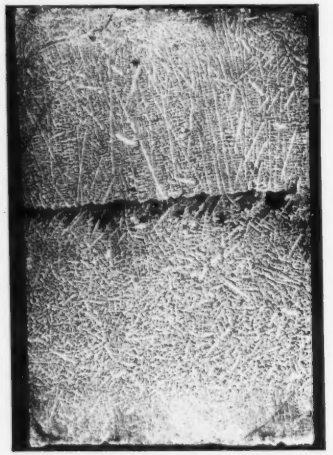


Casting *F*

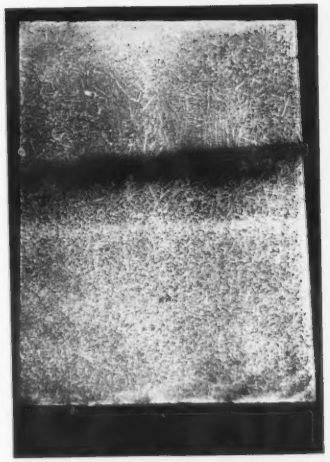
Fig. 9—Macrostructures of castings C, D, E, and F



Casting *C*



Casting *D*

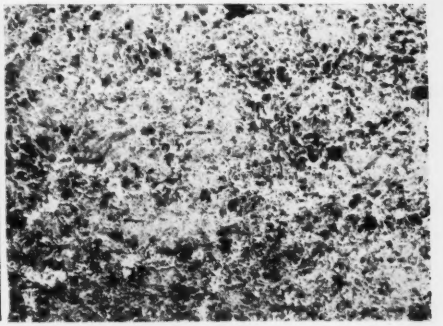


Casting *E*

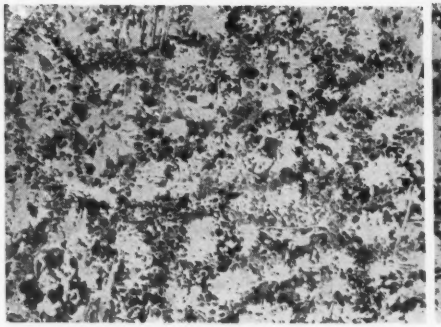
Casting *F*

Fig. 10—Macrostructures of portions of axial faces of castings *C*, *D*, *E*, and *F*

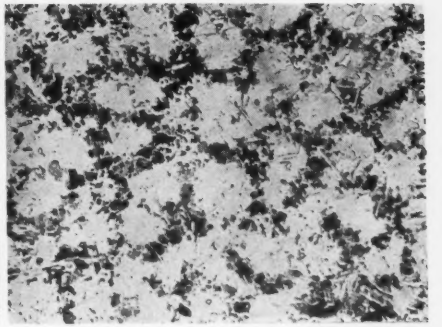
(a) Columnar region



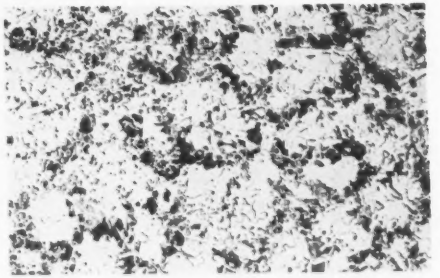
(b) egregated area



(c) Dendritic area below segregate



(d) Horizontal light zone

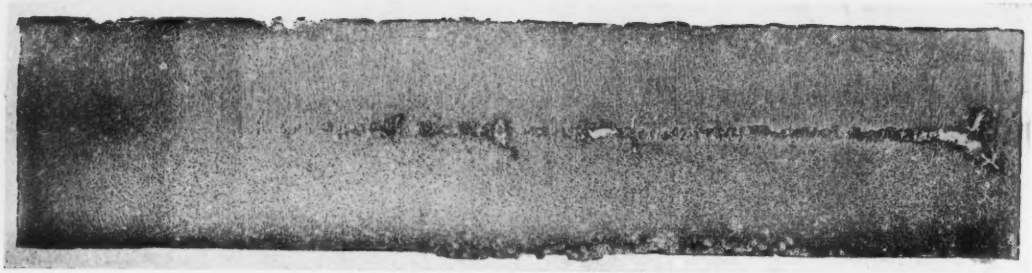


(e) Area below (d)

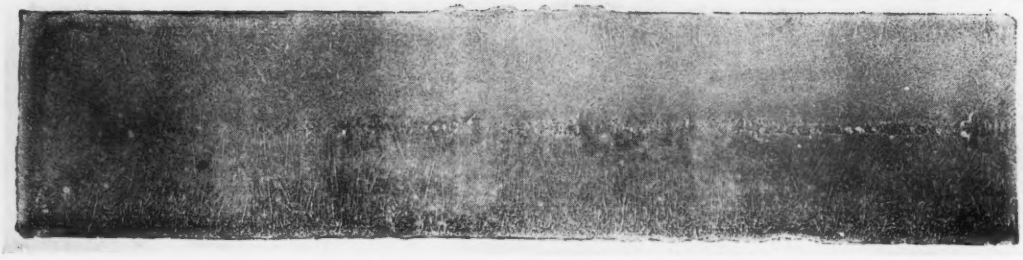
Fig. 11—Microstructures of casting E

Upper Casting Face

Feeder End



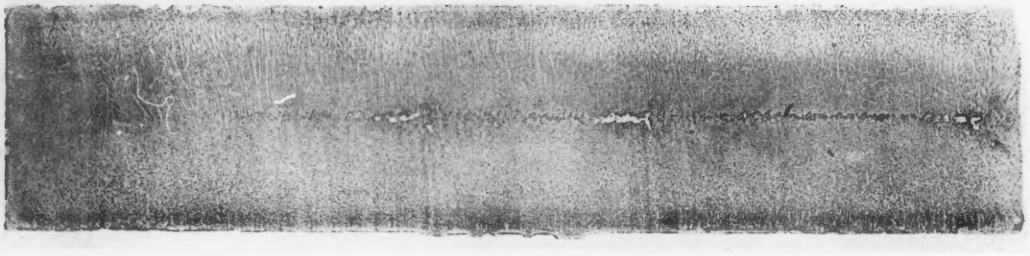
Casting *G*



Upper Casting Face

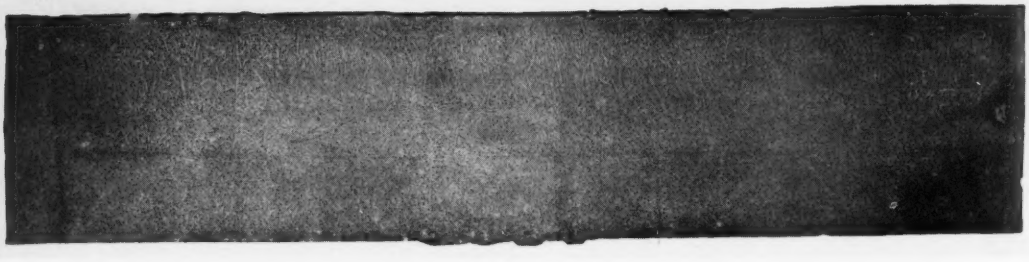
Casting *H*

Upper Casting Face



Casting *I*

Upper Casting Face



Casting *J*

Fig. 12—Macroprints of feeder heads of castings G, H, I, and J

indicated by the symbols *A* and *B*, 20, 21, and 22, in Fig. 2.

The results obtained were as follows :

Position in Casting *A*	Density, g./ml.	Position in Casting *B*	Density, g./ml.
*A*20	7·830	*B*20	7·814
*A*21	7·830	*B*21	7·814
*A*22	7·830	*B*22	7·814

The macrostructures were developed by etching with a solution of 3% nital on slices *A* and *B*, 18 and 19 after the diamond pyramid hardness determinations had been made. The division into upper and lower zones revealed in the sulphur prints was confirmed. It was also confirmed that central segregates were present in the specimens prepared from the positions near the feeder heads (*A*18 and *B*18), but absent in the specimens near the end of each casting (*A*19 and *B*19).

The microstructures were examined at various positions along the slices etched for macro-examination, and a few typical photomicrographs are shown in Fig. 6.

Discussion of Results

A notable feature in these castings was the occurrence of a columnar dendritic structure in the upper half, and an equi-axial structure in the lower half. A theory that the equi-axial crystals in the lower portion of the casting were produced by crystallization from nuclei introduced as a result of crystallites, falling from the upper regions during the early stages of solidification, was supported by the higher carbon, sulphur, and phosphorus contents, and higher hardness and tensile strength of the upper zone of casting *A*. This was not completely borne out in casting *B*, although differences in the same direction were observed in the carbon content and hardness values.

Corresponding to this slightly higher hardness of the upper zone of casting *A* (an average difference of nine Brinell units), the test-pieces prepared parallel to the length of the casting (*A*11 and *A*15) gave a tensile strength which was 2 tons/sq. in. higher in the upper zone than in the lower zone (31·6 and 29·6 tons/sq. in. respectively). The tensile properties of casting *B* were affected by porosity, so that comparison of the tensile properties of the upper and lower zones was not justified.

As would be expected, the ductility values of the test-pieces prepared across the depth of both castings were lower near the feeding neck than further along the castings, where the central aggregate was less prominent.

No differences were observed in either microstructure or density between the upper and lower zones of either of the castings (*see* Fig. 6). In the unetched condition the non-metallic inclusions were observed to be mainly composed of manganese sulphide in nodular and angular forms, and were dispersed at random. There was no evidence of intergranular films or chain-like formations of the inclusions. The segregates occurring in the middle portions of sections *A*18 and *B*18 were defined by an abundance of manganese sulphide inclusions, and a larger proportion of pearlite than that present in the upper and lower zones of the castings (*see* Fig. 6). These segregates had higher hardness values than any other portions of the castings.

(*b*) 0·28% CARBON STEEL CAST AT DIFFERENT TEMPERATURES

Experimental Details

A series of four castings was prepared by Mr. Dawson, from a 10-cwt. acid high-frequency furnace in Messrs. Hadfield's works, to the following composition :

C, %	Si, %	S, %	P, %	Mn, %	Cr, %	Ni, %
0·28	0·39	0·031	0·021	0·86	0·15	0·22

The four castings, made from the same melt of steel, were cast under the standard conditions, *viz.*, 4 in. square, 18 in. long, through a 1-in. dia. runner

Table II

MECHANICAL PROPERTIES OF CASTINGS *A* AND *B*

Position in Casting	Direction	Tensile Properties			
		Yield Point, tons/sq. in.	Ultimate Tensile Strength, tons/sq. in.	Elongation on $4\sqrt{\text{Area}}$, %	Reduction in Area, %
Casting *A*					
***A*10 Near feeder**	**Across the depth**	**15·6**	**30·8**	**17**	**22**
***A*16 Near middle**		**15·0**	**30·6**	**21**	**31**
***A*17 Near end**		**15·6**	**30·4**	**25**	**48**
***A*11 Upper zone**	**Parallel to the length**	**15·0**	**31·6**	**17**	**23**
***A*13 Middle**		**16·2**	**28·4**	**11**	**20**
***A*15 Lower zone**		**16·0**	**29·6**	**16**	**24**
Casting *B*					
***B*10 Near feeder**	**Across the depth**	**21·2**	**37·2**	**9**	**17**
***B*16 Near middle**		**20·8**	**35·8**	**15**	**20**
***B*17 Near end**		**21·0**	**37·0**	**15**	**19**
***B*11 Upper zone**	**Parallel to the length**	**21·6**	**30·0**	**8**	**14**
***B*13 Middle**		**Porous**	...	...	...
***B*15 Lower zone**		**20·6**	**36·6**	**17**	**20**

from a whirl-gate head. The steel was killed with 0·1% of aluminium and the moulds were of dry sand. Before tapping the furnace, bath temperatures were taken by an immersion thermocouple, the object being to tap out at the maximum desirable temperature, thereby running the castings as far as possible at predetermined temperatures as the steel cooled down. The temperature of the steel in the furnace just before tapping was 1694° C., and two minutes later its temperature in the ladle was 1653° C. At this stage the immersion thermocouple failed, and temperatures had thereafter to be taken by an optical pyrometer. The castings were poured ' over the lip ' in order to facilitate the use of the immersion thermocouple, but, as mentioned, an optical pyrometer was actually employed. The temperatures of the liquid steel during casting were as follows :

Casting	Estimated Casting Temp., ° C.
C	1645
D	1615
E	1520
F	1495

In confirmation of the very low casting temperature of the last casting, it was observed that the molten steel was very sluggish.

All the castings were annealed from a temperature of 940° C. before sectioning, during which operation care was taken to ensure that the saw was properly just off the centre-line, so that one true half from each casting was obtained. Figure 7 shows the four sulphur prints which were obtained, and Fig. 8 shows sulphur prints of the sections taken of the four feeding heads. Figure 9 is a reproduction of the ink prints taken from the four etched casting surfaces, to reveal their internal macrostructure.

Results of Metallurgical Examination

A further examination of the four sections of the castings was then undertaken by Dr. Northcott, who determined the tensile properties in two transverse and two longitudinal positions from each casting, the variations in chemical composition at different parts of the castings, and the macrostructures and microstructures at selected regions across the sections of the castings. Samples for these last tests were obtained from the axial face at positions representative of the upper and lower halves of each casting parallel to the length, and two others transversely from the two ends of the castings. The test-pieces had a diameter of 0·252 in., with a gauge length of 0·89 in. The yield point, ultimate tensile strength, percentage of elongation and percentage of reduction in area were determined. The end test-piece, near the feeder in each of the two castings *C* and *F*, showed a trace of porosity, so that further adjacent test-pieces were cut from these regions, and the figures reported are those for the sound test-pieces. The mechanical properties obtained by these tests are shown in their corresponding positions in the castings in Table III.

For the determination of the chemical composition three samples were drilled from the columnar region, *i.e.*, from the upper, middle, and lower zones of the castings. In addition, four samples for micro-analysis were obtained from the slice and used for the macro-examination of casting *E* in positions representing the columnar dendrites, the segregate, the narrow horizontal zone, and the granular zone below the horizontal zone. These chemical analyses are shown in Table IV in the positions in the castings from which they were taken.

To study the macrostructure, a slice 3-in. wide, covering the full depth of the casting, was cut adjacent to the central tensile test positions, and on the feeder-end side of each of the four castings. (*See* Fig. 10.) Since there was particular interest in casting *E*, showing the horizontal zone below the segregate, further attention was paid to this casting. Surfaces for micro-examination were obtained from the side of the macro slice away from the feeder end of casting *E*, and Fig. 11 shows five typical structures, all within 1·25 in. of each other, as follows :

Table III

MECHANICAL PROPERTIES OF CASTINGS *C*, *D*, *E*, AND *F*.

Casting	Test	Yield Point, tons/sq. in.	Ultimate Tensile Strength, tons/sq. in.	Elongation on 0·89 in., %	Reduction in Area, %	Diagrammatic Position of Specimens in Castings
C	C1	20·2	33·3	11·0	10·0	Feeder end
	C2	19·0	33·9	17·0	21·0	
	C3	20·2	34·6	19·0	21·0	2, 4, 1, 3 — 1x
	C4	21·4	34·5	26·0	30·5	
	C1x	20·0	34·6	16·0	9·0	
D	D1	22·8	35·2	13·5	17·5	
	D2	22·0	34·9	20·0	21·5	2, 4, 1, 3
	D3	20·0	34·9	21·5	22·5	
	D4	21·2	34·7	22·5	22·5	
E	E1	21·4	33·3	19·0	29·5	
	E2	22·6	35·6	20·0	19·0	2, 4, 1, 3
	E3	21·0	33·8	20·0	21·0	
	E4	19·6	33·1	21·5	26·5	
F	F1	19·4	21·8	3·5	2·5	
	F2	21·4	36·6	17·0	17·0	
	F3	18·8	33·6	19·0	21·0	2, 4, 1, 3 — 1x
	F4	19·2	33·4	19·0	19·5	
	F1x	19·0	33·4	14·5	14·5	

(*a*) The columnar area just above the segregate
(*b*) The segregate area
(*c*) The coarse dendritic area immediately below the segregate
(*d*) The horizontal zone of fine structure
(*e*) The nuclear zone just below (*d*).

Photomicrographs of polished surfaces showed that the horizontal light zone had relatively few non-metallic inclusions as compared with the whole section of the casting.

Discussion of Results

From the macroprints in Fig. 9 a columnar type of dendritic growth is revealed in the upper halves of the castings. These columnar dendrites run to the central segregated zone, but the distance from the top casting face, from which they commence their growth, clearly depends upon the casting temperature; the lower the casting temperature the greater is this distance. The two castings which were cast at higher temperatures, *C* and *D*, reveal, below the line of segregation, an area of randomly oriented dendritic crystals, whereas in castings *E* and *F*, which were cast at lower temperatures, this area appears cellular and of relatively fine structure. A feature most well-defined in casting *E* is the roughly **V**-shaped area extending two-thirds of the way down the casting from the feeder end, and of a randomly oriented type of crystallization inter-spaced between the upper columnar dendrites and the cellular or nuclear type of structure in the lower part of the casting. The sharpest demarcation occurs in the junction of the segregate with the columnar dendrites growing down from the upper part of the casting, and there is no noticeable penetration of these columnar dendrites into the segregates. The other structural zones in this casting merge gradually from one to the other.

The effect of casting temperature is most marked upon the sharpness and position of the line of segregation, which is presumably the last position in the casting to solidify. The lower the casting temperature, the less well-defined this line became, *i.e.*, the residual segregates were more dispersed, and also the segregate line was raised more from the geometric central axis of the casting and made to incline down from the feeder end. This tendency is most marked in casting *F*, which was cast at the lowest temperature, and whose segregate at the feeder end commences nearer to the upper corner of the casting than to its central axis. All four castings show some unsoundness in the segregate area, but most markedly in casting *F*. In castings *C* and *D*, at the ends remote from the feeder (*i.e.*, where the end wall of the casting would introduce some complicating horizontal thermal gradients) there is some evidence of ' pyramid ' growth, similar to that found in ingots. Castings *C* and *D* were cast at the higher temperatures.

The chief points of difference between the microstructures are the traces of columnar structure in Fig. 11*a*, the large proportion of pearlite in Fig. 11*b*, the pearlitic network in Fig. 11*c*, *d*, and *e*, and the general freedom from isolated pearlite inside the pearlitic network of the narrow light horizontal zone shown in Fig. 11*d*, as compared with the regions above and below this light zone shown in Fig. 11*c* and *e*, respectively. This light zone was also freer from non-metallic inclusions.

The differences between the chemical compositions across the sections of all four castings indicate that the lowest positions are of greatest purity. These differences are well shown by the micro-analyses taken from casting *E*. (*See* Table IV.) Not only do the lowest portions contain much less carbon, sulphur, and phosphorus, but the highly impure

Table IV

VARIATION IN COMPOSITION OF CASTINGS *C*, *D*, *E*, AND *F*

Feeder End of Castings	C, %	Si, %	Mn, %	S, %	P, %			
Casting *C*								
Upper	0·29	0·46	0·85	0·032	0·025			
Middle	0·25	0·46	0·87	0·033	0·024			
Lower	0·24	0·46	0·84	0·032	0·022			
Casting *D*								
Upper	0·28	0·50	0·83	0·035	0·027			
Middle	0·28	0·50	0·86	0·033	0·027			
Lower	0·26	0·50	0·87	0·034	0·027			
Casting *E*								
						C, %	S, %	P, %
Upper	0·26	0·47	0·87	0·030	0·030	[1] 0·31	0·038	0·035
Middle	0·24	0·47	0·83	0·029	0·029	[2] 0·51	0·082	0·067
						[3] 0·26	0·020	0·022
Lower	0·25	0·47	0·87	0·027	0·027	[4] 0·27	0·030	0·023
	[1] Columnar Dendritic Zone		[2] Segregated Zone		[3] Horizontal Zone		[4] Granular Zone	
Casting *F*								
Upper	0·28	0·47	0·88	0·029	0·032			
Middle	0·26	0·47	0·84	0·028	0·028			
Lower	0·26	0·47	0·86	0·026	0·026			

state of the segregate zone is well shown. Further, these micro-analyses show that the narrow light horizontal line below the segregate has a higher purity than any other part of the casting.

(c) 0·15% CARBON STEEL CAST AT DIFFERENT TEMPERATURES

Experimental Details

Four standard castings with whirl-gate heads were made by the David Brown Foundries Co., from four consecutive melts from a basic high-frequency furnace. The charge for each melt was similar, and consisted of Armco iron and a specially selected scrap ; the 250-lb. melts were finally deoxidized with 8 oz. of aluminium. Before tapping, the temperature in the furnace was checked and adjusted to give the required ladle temperature. The steel was cast from a stoppered ladle through a nozzle of 1 in. dia., and temperatures were taken with an immersion thermocouple in the ladle during the casting operation. The casting temperatures of the four successive melts for the four castings were as follows. The castings are arranged in order of casting temperature, together with their chemical compositions :

Casting Symbol	Melt No.	Casting Temp., °C.	Composition C, %	Si, %	Mn, %	S, %	P, %
G	E2954	1640	0·16	0·26	0·68	0·022	0·019
H	E2951	1575	0·15	0·24	0·62	0·022	0·017
I	E2952	1555	0·15	0·26	0·67	0·022	0·015
J	E2953	1535	0·15	0·26	0·66	0·022	0·015

The castings were made in Randupson-type moulds, sand bonded by cement. After cooling to room temperature the castings were taken from the moulds and were heated to 950° C., at which temperature they were soaked for 9 hr., and then furnace-cooled. As with the other castings the heads were then removed and a vertical section along the centre-line of the full length of 18 in. was examined by macro-printing. Macroprints were taken of the whole section of the four castings and are shown in Fig. 12, and Fig. 16 shows the macrostructure of a portion of each of the four castings.

Results of Metallurgical Examination

The detailed metallurgical examination, was conducted by Mr. Evans. A macro-examination was made along the side surface of a slice cut from the half section, marked as position *M*2 in Fig. 13, which shows the positions from which all the test samples were taken. Thus, this examination differs from the earlier ones in that the transverse structure was studied as well as the longitudinal structure. These transverse macrostructures are shown in Fig. 17.

Sulphur prints were taken on a portion of each casting, the position being indicated as *S*4 in Fig. 13. The macrostructure of the longitudinal face of each casting, as defined by the ink print, was confirmed by the sulphur prints, and therefore these latter prints are not reproduced in the Report. The dark horizontal band shown in the ink print of casting *J*, approximately $\frac{1}{2}$ in. from the middle, and shown clearly in Fig. 12, was shown in the sulphur print as a zone lighter in colour than the remainder of the print.

Complete chemical analysis of the different zones was made, sufficient quantities of steel for the analysis being obtained by drilling two holes, side by side, to a depth of $\frac{1}{2}$ in. by means of a $\frac{5}{8}$-in. dia. drill. These positions are marked *A*1, *A*2, and *A*3 in Fig. 13.

The following are the results obtained from the analysis :

Casting and Position		Zone	C, %	Si, %	Mn, %	S, %	P, %
G	*A*1	a	0·13	0·25	0·67	0·015	0·018
G	*A*2	b	0·13	0·26	0·66	0·016	0·018
H	*A*1	a	0·11	0·22	0·61	0·016	0·018
H	*A*2	b	0·12	0·23	0·60	0·014	0·018
I	*A*1	a	0·12	0·27	0·66	0·015	0·018
I	*A*2	b	0·12	0·27	0·67	0·016	0·017
I	*A*3	c	0·12	0·27	0·68	0·015	0·017
J	*A*1	a	0·11	0·28	0·64	0·016	0·018
J	*A*2	b	0·12	0·28	0·64	0·016	0·018
J	*A*3	c	0·11	0·28	0·62	0·015	0·016

(a) Upper columnar dendritic zone
(b) Intermediate equi-axial zone
(c) 'Cellular' zone

Diamond pyramid hardness surveys were made across the depth of each casting in the position marked *H*3 in Fig. 13.

Brinell hardness determinations, using a 10-mm. ball and a 1000-kg. load, were made on each of the tensile pieces marked in positions *T*1, *T*2, and *T*3 in Fig. 13. All the results obtained for the hardness determinations are shown together in diagrammatic form in Fig. 14, each HD/30 point representing the average of four measurements. In this diagram a continuous curve has been drawn through each set of the numerous points showing the diamond pyramid hardness, and the Brinell hardness figures are inserted in their respective positions across the castings and distinguished by showing them in rectangular frames.

Tensile properties, including the yield point as estimated by means of dividers, were determined on test-pieces machined from three positions at the middle of the length of the castings (except in casting *G* which was only examined at two positions). These positions are indicated in Fig. 13 as *T*1, *T*2, and *T*3. The test-pieces had a diameter of 0·252 in. and a gauge length of 0·89 in.

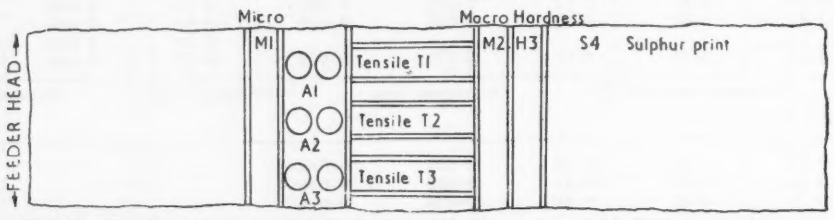


Fig. 13—Section across casting *G*, *H*, *I*, and *J*, showing position of test specimens

The following are the results obtained from the different zones, the test-pieces all being parallel to the direction of feeding :

Casting and Position	Description of Zone	Yield Point, tons/sq. in.	Ultimate Strength, tons/sq. in.	Elong. on $4\sqrt{\text{area}}$, %	Reduction in area, %
G *T*1	Columnar	15·4	27·7	35·0	44·0
G *T*2	Equi-axial	15·4	27·3	27·0	37·0
H *T*1	Columnar	15·6	27·1	36·0	42·0
H *T*2	Equi-axial	15·0	26·9	31·0	37·0
H *T*3	Columnar	15·2	26·9	33·0	57·0
I *T*1	Columnar	15·8	28·0	37·1	53·0
I *T*2	Equi-axial	15·6	27·8	32·0	51·0
I *T*3	'Cellular'	15·4	27·5	38·0	53·0
J *T*1	Columnar	15·8	28·1	37·1	54·5
J *T*2	Equi-axial	15·0	27·3	36·0	48·0
J *T*3	'Cellular'	15·6	27·2	35·0	52·0

Micro-examinations were made across the depth of the slices cut from position *M*1 marked in Fig. 13. Typical photomicrographs are reproduced in Fig. 18.

Discussion of Results

All four castings showed some degree of unsoundness, as will be seen from Fig. 12, but the extent and location of the unsoundness show some correlation with the casting temperature. The block *G*, cast at the highest temperature, shows the most marked unsoundness, which is coarse and localized in the centre and near the feeder head. The two blocks, *H* and *I*, cast at the intermediate temperatures, show an unsoundness which is finer and fairly evenly distributed along the central line of the castings, but this unsoundness is not obviously related to casting temperature. The block *J*, cast at the lowest temperature, appears sound, with the exception of a small area near to the feeder head. Thus, high casting temperature, which means a relatively slow rate of solidification, seems to result in less efficient feeding from the feeder head and in a greater degree of localization of unsoundness within the casting.

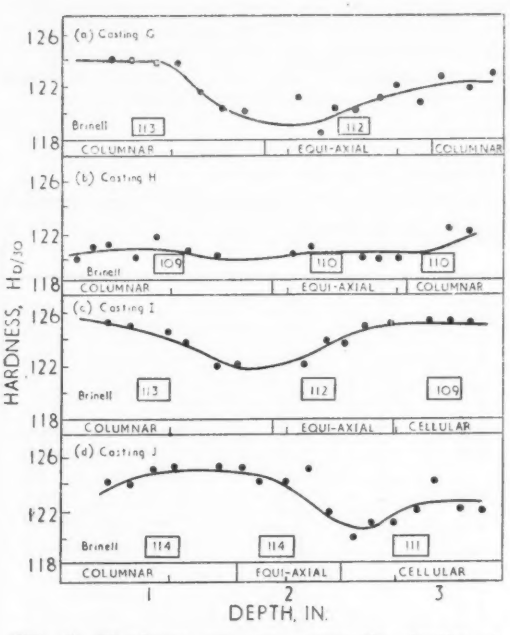


Fig. 14—Hardness surveys across the depths of castings *G*, *H*, *I*, and *J*

If attention is concentrated upon the variation in macrostructure across the depth of the castings, several points of interest will be seen from Figs. 12, 16, and 17. Each block shows a dendritic growth from the upper surface of the casting, and although for castings *G*, *H*, and *I* the extent of this growth is nearly to the centre of the casting, *i.e.*, nearly 2 in., the block J, cast at the lowest temperature, has an upper dendritic growth of only 1·6 in. This has the effect of giving an uplift to the 'centre' line of the casting, and if it is assumed that this centre line corresponds to the last region in the casting to solidify, then it means that, with the small superheat available in the liquid steel for casting block *J*, the upper and lower faces of the mould have a marked differential cooling effect, which is not observable for the other blocks, where presumably the greater superheat has provided more time to accomplish thermal adjustment. Below the centre line of each casting there is a region containing short dendrites which are randomly oriented, and which are therefore referred to as "equi-axial dendrites." The depth of this region is progressively less as the casting temperature is lowered, being 1·6 in. for casting *G*, and only 0·9 for casting *J*. The fact that in this region the dendrites grow to as long as half-an-inch implies that nuclei for initiating crystallization are relatively scarce, and the fact that the dendrites are randomly oriented implies the absence of any well-defined thermal gradient during this stage of the solidification of the castings. Below this region the structure appears to depend sharply upon the casting temperature. Castings *G* and *H* show a columnar dendritic growth from the lower mould face up to the equi-axial region, and castings *I* and *J*, cast at lower temperatures, show a fine cellular structure, such as would be expected to appear from incipient crystallization from many closely spaced nuclei. Hence the term 'nuclear,' which is frequently used to describe this type of structure. The fact that the blocks cast with the greater superheat do not show this type of structure could mean that they had fewer nuceli, or that the delayed solidification favoured by the superheat has assisted the growth of dendrites from the casting wall. Whatever the mechanism, it is in accord with the theory and general experience that slower crystallization should favour larger crystal growth.

The following data enable comparison of the various zones to be made :

Casting Symbol	Casting Temp., °C.	Upper Zone Depth, in. Columnar Dendrites	Intermediate Zone Depth, in. Equi-axial Dendrites	Type of Lower Zone and Depth, in.
G	1640	1·85	1·60	Columnar dendrites 0·55
H	1575	1·90	1·20	Columnar dendrites 0·90
I	1555	1·95	1·00	Cellular 1·00
J	1535	1·60	0·90	Cellular 1·50

Figure 15 shows, in diagrammatic form, the effect of casting temperature upon the various structures disclosed in these four castings.

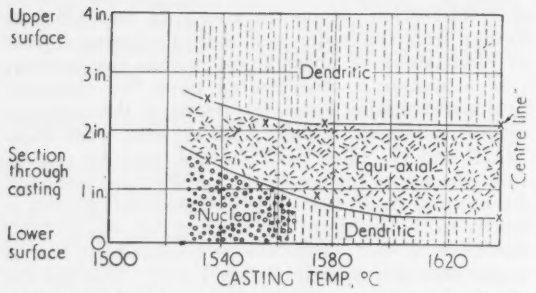


Fig. 15—Effect of casting temperature on structure across castings

In regard to the hardness values and the mechanical properties, the only reasonably consistent points that emerge are that the columnar dendritic zones are slightly harder and have correspondingly higher ultimate tensile strengths, and that these zones are also somewhat more ductile. However, the correlation between ductility and macrostructure is considered to be unreliable for these castings, since they had appreciable internal porosity, and, in consequence, some of the fractures obtained on the test-pieces were irregular or occurred near to the punch mark. Casting temperature apparently has no effect upon the yield point or the ultimate tensile strength of the castings, but it is of interest to note that the most consistent and highest average values for elongation and reduction in area are obtained from the castings *I* and *J*, cast at the lower temperatures.

The non-metallic inclusions in all sections examined were mainly of manganese sulphide, and occurred in the nodular or angular form. Intergranular sulphide films were absent. The inclusions were distributed uniformly throughout the different zones, except that, as would be expected, more were present in the central segregated zones observed in castings *G*, *H*, and *I*. Examination of the horizontal zone dividing the nuclear and equi-axial zones of casting *J* did not reveal any marked change in microstructure. In confirmation of the results obtained on sulphur printing, this zone appeared to contain fewer manganese-sulphide inclusions than either of the adjacent nuclear or equi-axial zones.

In the etched condition only slight differences in the ferrite–pearlite microstructures of the various zones were observed. (*See* Fig. 18.) The columnar zones, whether in the upper or lower portions of the castings, show a slight dendritic pattern of the ferrite and pearlite, and the equi-axial and nuclear zones show more uniformly dispersed islands of pearlite in ferrite. In addition to the more numerous manganese sulphide inclusions in the central segregated zones, more pearlite was observed in these zones.

(d) 0·54% CARBON-STEEL CASTINGS, *K*, *L*, *M*, AND *N*

Experimental Details

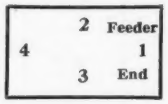
Castings *K*, *L*, *M*, and *N* were made from a 55-cwt. melt in an acid side-blown converter by Messrs. Catton & Co., to the following composition: C 0·54%, Si 0·40%, Mn 1·09%, S 0·047%, and P 0·041%.

All the temperatures were taken by immersion pyrometer, the temperature of the iron from the cupola being 1355° C., and the temperature of the blown metal in the converter 1730° C. The additions made during the steelmaking operation included 30 lb. of ferrosilicon during the blow, 90 lb. of silicon-manganese, 19 lb. of ferromanganese, 6 cwt. of cupola metals as finishings to the converter, and 12 lb. of aluminium to the ladle. The melt of the finished steel was tapped into a stoppered ladle, and block *K* was cast through the nozzle of this ladle. Half a ton of liquid steel was then poured from the ladle into a smaller lip-pouring ladle, from which the other three blocks *L*, *M*, and *N*, were cast consecutively at lower temperatures. The temperature in the larger ladle before casting any of the blocks was 1630° C., and temperatures of the pouring stream of liquid steel during the casting of the four blocks were:

Table V

MECHANICAL PROPERTIES OF CASTINGS *K*, *L*, *M*, AND *N*

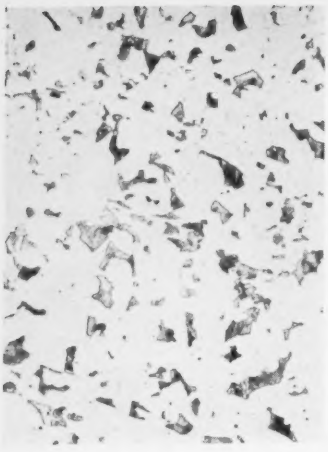
Casting	Test	Yield Point, tons/sq. in.	Ultimate Tensile Strength, tons/sq. in.	Elongation on 0·89 in., %	Reduction in Area, %	
K	*K1*	12·8	36·6	3·4	1·6	
	K2	25·8	41·2	5·6	2·4	
	K3	21·8	43·8	4·5	1·6	
	K4	27·3	46·1	4·5	1·6	
L	*L1*	...	33·7	2·2	0·6	
	L2	31·1	41·2	2·2	2·4	
	L3	26·6	37·0	4·5	1·6	
	L4	30·4	44·7	4·5	4·0	
M	*M1*	...	15·3	2·2	...	
	M2	27·5	43·2	5·6	4·0	
	M3	28·0	45·4	7·9	5·4	
	M4	19·6	43·5	4·5	2·6	
N	*N1*	27·5	36·0	3·4	1·8	
	N2	21·9	39·8	4·5	3·2	
	N3	22·2	43·6	7·9	5·4	
	N4	24·2	40·8	4·5	4·0	



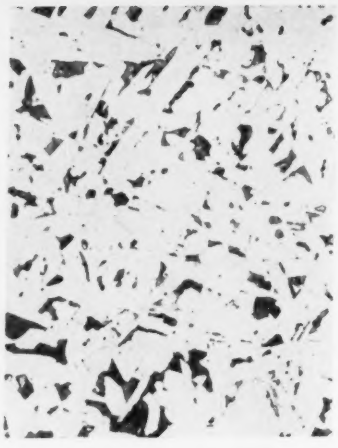
Diagrammatic position of specimens in casting

Fig. 16—Macrostructures of portions of castings G, H, I, and J

Fig. 17—Transverse macrostructures of castings G, H, I, and J

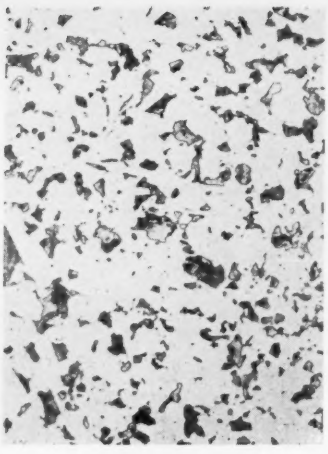


(a) Equi-axial-dendritic zone

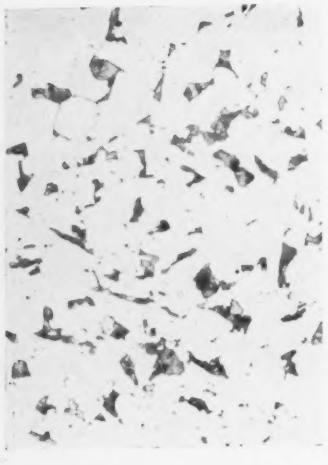


(b) Lower columnar dendritic zone

Casting *G*

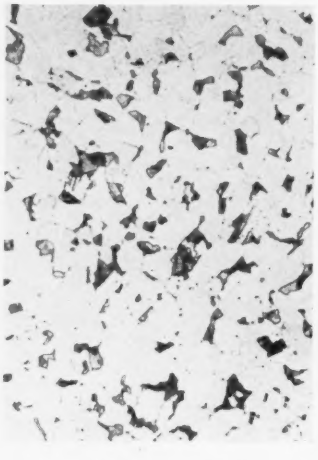


(c) Central segregate

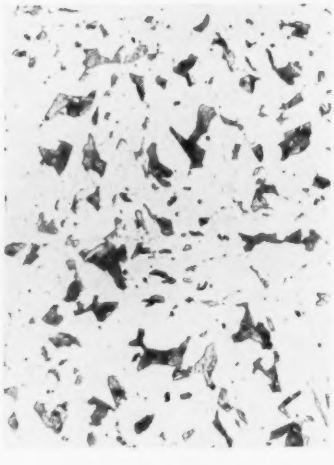


(d) Equi-axial-dendritic zone

Casting *H*

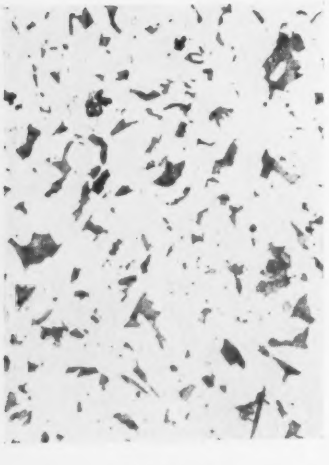


(e) Lower columnar dendritic zone



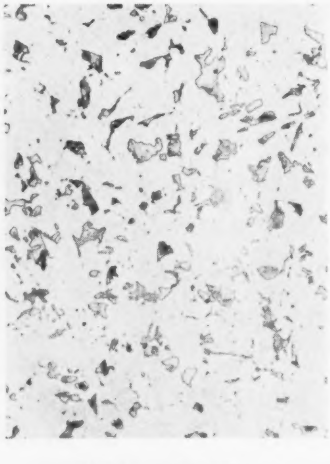
(f) Columnar dendritic zone

Casting *I*



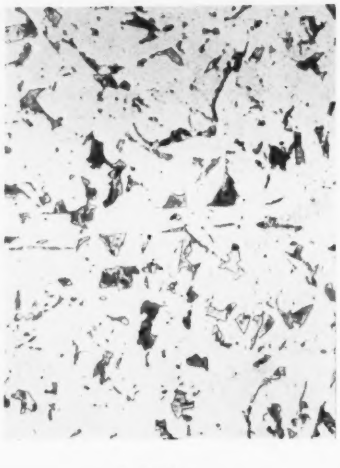
(g) Cellular zone

Casting *I*



(h) Columnar dendritic zone

Casting *J*



(i) Cellular zone

Fig. 18—Microstructures of castings G, H, I, and J

Melting and Metallurgical Committee]

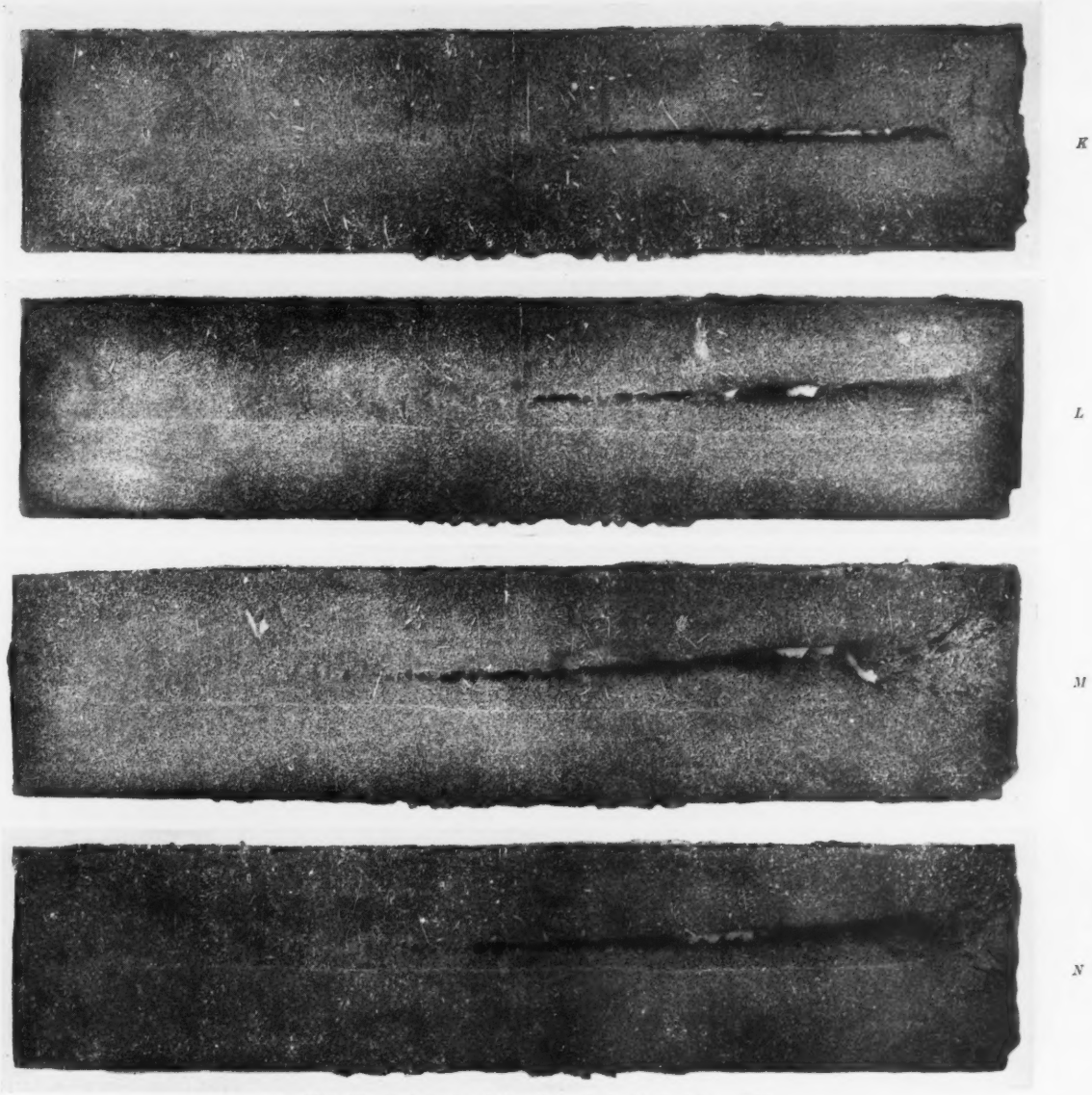


Fig. 19—Sulphur prints of castings *K*, *L*, *M*, and *N*

Fig. 20—Macro-print of section of casting *N*

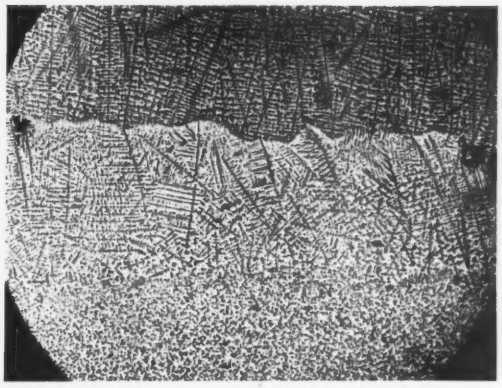


Fig. 21—Enlarged view of portion of Fig. 20

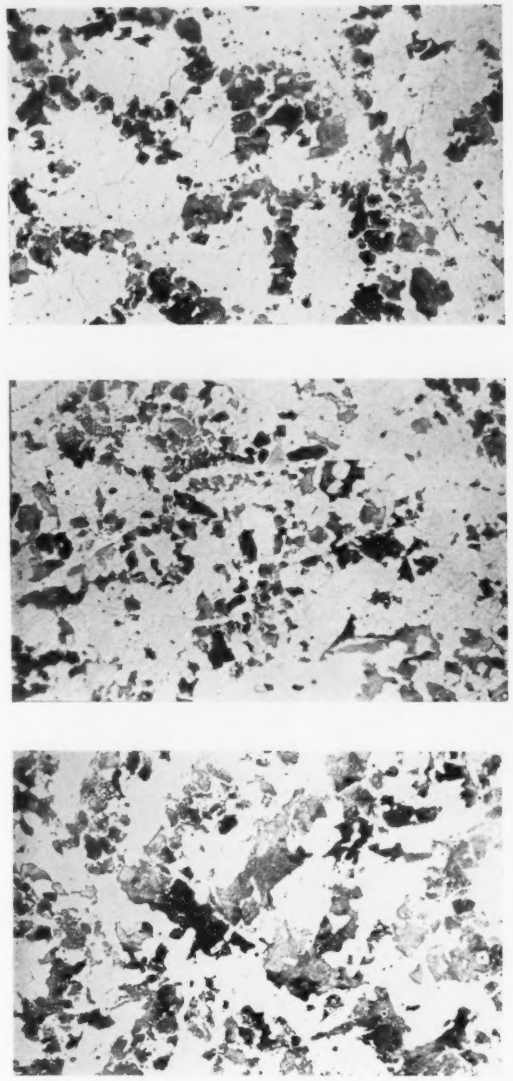
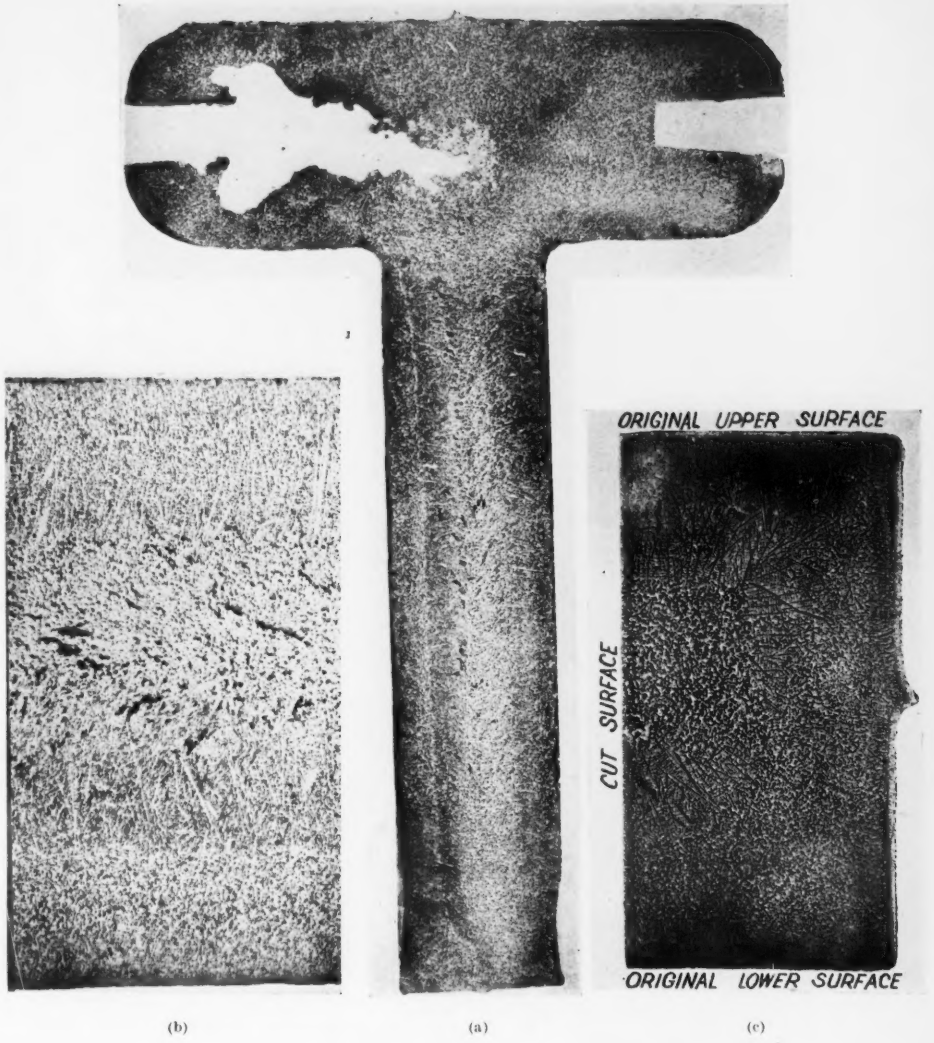


Fig. 23—Typical microstructures of casting *O*: (a) Columnar dendritic zone; (b) Equi-axial dendritic zone at the original lower cast surface; (c) Segregated part of the casting × 100



(b) (a) (c)

Fig. 22—(a) Sulphur print of the horizontally cast plain-carbon steel block (Casting O); (b) Enlarged portion of (a); (c) Macrostructure of half of transverse section of casting O

Casting Symbol	Casting Temp., °C.
K	1580
L	1508
M	1496
N	1485

It was observed that the steel was rapidly solidifying in the small ladle during the casting of the last two blocks, and it was not possible to take an immersion temperature during the casting of the last block, *N*, the figure above being an estimated value.

The castings were of the standard block type, cast through a 1-in. dia. runner into a whirl-gate head and through an ingate with a diameter of 3·5 in. The moulds were formed in green sand, and the blocks, after stripping from the moulds, were not given any heat-treatment before sectioning and examination.

Results of Metallurgical Examination

Dr. Northcott undertook the following metallurgical examination of these four blocks.

Sulphur prints of the macro-etched vertical longitudinal section of the blocks were made, and Fig. 19 shows the macrostructures. Attention was concentrated upon the middle portion of casting *N*, that cast at the lowest temperature, as this portion revealed, in a well-defined manner, the typical zones found in all of the castings. Figure 20 shows a macroprint of this section, and Fig. 21 shows a somewhat enlarged view of a portion of the same area.

Mechanical properties were determined at four positions from each casting, corresponding to the longitudinal extremities and to two typical zones across the middle section of the castings. The results obtained are given, with a diagrammatic indication of the respective positions in the castings from which the test-bars were cut, in Table V.

The chemical composition was determined across the sections of the castings. Drillings were taken from three positions, corresponding to the top, middle, and bottom of each casting. The results obtained are as follow :

Casting and Position		C, %	Mn, %	S, %	P, %
K	Top	0·56	1·09	0·051	0·042
K	Middle	0·51	1·07	0·047	0·040
K	Bottom	0·51	1·09	0·051	0·042
L	Top	0·58	...	0·051	0·045
L	Middle	0·51	1·06	0·051	0·042
L	Bottom	0·48	1·06	0·051	0·043
M	Top	0·56	1·06	0·052	0·041
M	Middle	0·54	1·07	0·052	0·043
M	Bottom	0·49	1·06	0·047	0·038
N	Top	0·58	1·09	0·052	0·040
N	Middle	0·49	1·07	0·051	0·038
N	Bottom	0·48	1·07	0·049	0·037

A more detailed study was made across the middle slice cut from casting *N*, with the following results :

Zone of Casting *N*	C, %	S, %	P, %
Columnar dendrites	0·55	0·052	0·052
'Central' segregates	0·92	0·218	0·159
Equi-axial dendrites below segregate	0·54	0·048	0·039
Narrow 'light' zone	0·48	0·035	0·029
Granular zone	0·48	0·044	0·042

Five samples of one-third of a gramme, for microchemical analysis, were taken as accurately as possible from the five distinct zones between the top and bottom of the section.

Discussion of Results

From the macrostructures shown in Fig. 19 a number of features are of interest :

(*i*) The casting cast at the highest temperature, *K*, shows distinct evidence of dendritic growth from the lower, as well as the upper surface, so that the equi-axial zone is restricted to a relatively smaller area below the 'central' segregate, which, for this casting, is on the true geometrical centre of the casting. This feature is also found in the other higher temperature castings of this Report, as will be seen by comparing castings *C* and *D* with *E* and *F* (Fig. 9), or castings *G* and *H* with *I* and *J* (Fig. 16).

(ii) The other three castings *L*, *M*, and *N*, all show a segregated centre displaced above the geometrical centre, and they also show a narrow light zone, or line, running somewhat below the geometrical centre. As will be seen from the analyses, the segregate is, as usual, a zone of high impurity with respect to carbon, sulphur, and phosphorus, whereas the lower light line is one of distinctly greater purity than the mean composition. The segregated centre is obviously the last portion of the casting to freeze, and this is confirmed by the porosity associated with it, but the manner of formation of the somewhat lower light line is not known. One clue is that it is not present in the highest temperature casting, *K*, but it is most accentuated in the lowest temperature casting, *N*. This is also confirmed in the other lower temperature castings of this Report, especially castings *E*, *F*, and *J*.

(iii) No well-defined conclusions can be drawn from the figures obtained for the mechanical properties, and though the lower equi-axial zones have a slightly greater ductility for the castings made at a lower temperature, *M* and *N*, this is accompanied by a slightly greater tensile strength also.

(e) 0·23% CARBON-STEEL CASTING INVERTED 3 MIN. AFTER FILLING THE MOULD

In view of the differences between the upper and lower structures of the castings so far detailed, it was decided to examine the effect of inverting a casting before freezing was completed. It was found that the initial or primary solidification was, as usual, dendritic from the upper face and equi-axial from the lower face, but after inversion equi-axial crystals grew on from the primary columnar dendrites, and columnar dendrites grew on from the primary equi-axial crystals. Thus, it was shown that the formation of the two types of crystal was associated with their relative vertical height in the casting, and not with the initial types of crystal formation on the upper and lower faces.

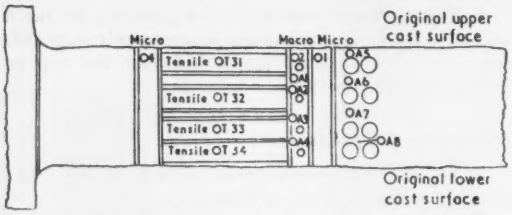


Fig. 24—Positions of test-pieces from casting *O*

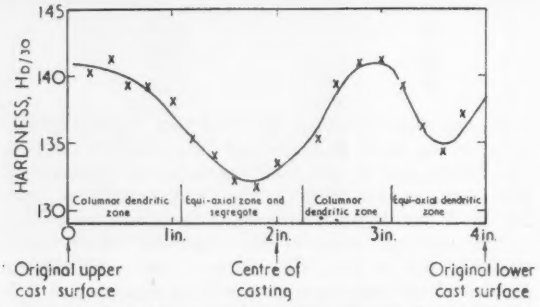


Fig. 25—Hardness survey taken across the depth of casting *O*

Experimental Details

The casting was made under the guidance of Mr. Gray at the works of the English Steel Corporation, Ltd. The casting was a normal 4-in. square block, 18 in. long, fed, as usual, from a whirl-gate head, but owing to the inversion, a double feeder head had to be used, so that when the casting had been inverted there was still a pressure-head of molten steel acting upon the casting. Figure 22*a* shows the section which was examined, together with the double feeder-head attached. The inversion of the casting was made through 180° about its longitudinal or major axis, and the section studied was a vertical longitudinal medium section.

The steel was made in an acid-electric furnace, and had the following composition :

Cast No.	C, %	Si, %	Mn, %	S, %	P, %
15442 N	0·23	0·24	0·53	0·045	0·043

The temperature of the steel in the furnace just before tapping was 1605° C., but the temperature in the ladle was not taken. The steel was finally deoxidized in the ladle with 0·09% of aluminium. The casting was made in a sand mould, and after the elapse of three minutes the mould was inverted and allowed to solidify completely in this position. After stripping from the mould the casting was annealed at 920° C. before sectioning. The selected cut face was ground and sulphur printed ; the sulphur print is reproduced in Fig. 22*a* and a portion of it in Fig. 22*b*.

Results of Metallurgical Examination

The following detailed metallurgical examination was undertaken by Mr. Evans.

A macro-examination of the middle portion of the section was made in order to ascertain the extent of the various zones in the cross-section. Figure 22*c* shows a transverse slice from the middle of the half section.

A preliminary survey of the variation in carbon content across the section was made by analysis of drillings taken to a depth of $\frac{5}{8}$ in. with a $\frac{1}{4}$-in. dia. drill at four selected positions, indicated by the symbols *OA*1 to *OA*4 in Fig. 24, which is a key diagram to all the tests made on this section. The results obtained were as follows :

Symbol	Position in Casting *O*	C, %
*OA*1	Upper or Primary Columnar Dendritic Zone	0·26
*OA*2	Upper or Secondary Equi-axial Dendritic Zone	0·24
*OA*3	Lower or Secondary Columnar Dendritic Zone	0·24
*OA*4	Lower or Primary Equi-axial Dendritic Zone	0·25

Complete chemical analysis was made at four additional positions indicated by the symbols *OA*5 to *OA*8. Drillings were taken to a depth of $\frac{5}{8}$ in. by means of a $\frac{1}{2}$-in. dia. drill, and the results obtained were as follows :

Symbol	Position in Casting *O*	C, %	Si, %	Mn, %	S, %	P, %
*OA*5	a	0·25	0·28	0·54	0·037	0·042
		0·26	0·29	0·53	0·038	0·041
*OA*6	b	0·23	0·28	0·52	0·031	0·040
		0·24	0·27	0·52	0·032	0·040
*OA*7	c	0·25	0·27	0·52	0·040	0·042
		0·26	0·27	0·53	0·039	0·041
*OA*8	d	0·24	0·27	0·52	0·038	0·042
		0·25	0·27	0·52	0·037	0·042

(a) Upper or primary columnar dendritic zone
(b) Upper or secondary equi-axial dendritic zone
(c) Lower or secondary columnar dendritic zone
(d) Lower or primary equi-axial dendritic zone

A diamond hardness survey was made across the two sections indicated by the symbols *O*1 and *O*4, and the Brinell hardness figures were also obtained on the tensile test blanks. The first diamond hardness survey (HD/30) was made on slice *O*1, and it was observed that the columnar dendritic zones were slightly harder than the equi-axial zones. Slice *O*4 was then examined at intervals of $\frac{1}{8}$ in. from the two outer surfaces of the casting, five measurements being made in a line at each position. The average hardness values at each position across the slice were plotted in relation to the variations in the macrostructure of the casting, as shown in Fig. 25.

Brinell hardness measurements, using a 3000-kg. load and a 10-mm. ball, were taken on the blanks cut for tensile tests from each zone, with the following results :

Symbol	Position in Casting	Brinell Hardness Numbers (and average)
*OT*31	Upper or Primary Columnar Dendritic Zone	152 154 (153) 153
*OT*32	Upper or Secondary Equi-axial Dendritic Zone	149 146 (147) 147
*OT*33	Lower or Secondary Columnar Dendritic Zone	158 156 (158) 160
*OT*34	Lower or Primary Equi-axial Dendritic Zone	150 149 (150) 151

Tensile tests were made on test-pieces having a diameter of 0·252 in., and a gauge length of 0·89 in. The test-pieces were cut parallel to the direction of feeding and from the four principal zones. The tests were made after normalizing the test-piece blanks from 890° C., and the following results were obtained :

Symbol	Position in Casting	Yield Point, tons/sq.in.	Ultimate Strength, tons/sq. in.	Elongation on $4\sqrt{\text{area}}$, %	Reduction in area, %
*OT*31	a	21·3	34·6	28·6	32·6
*OT*32	b	19·3	31·8*	11·0	23·9
*OT*33	c	21·9	35·3	18·7†	23·9
*OT*34	d	19·9	33·9	28·6	30·4

(a) Upper or primary columnar dendritic zone
(b) Upper or secondary equi-axial dendritic zone
(c) Lower or secondary columnar dendritic zone
(d) Lower or primary equi-axial dendritic zone

* Fractured at defect in parallel position
† Fractured close to gauge mark

A study under the microscope was made across the middle of the half section, and typical etched structures are shown in Fig. 23.

Discussion of Results

The sulphur print (Fig. 22*a*) and the macrostructure (Fig. 22*b*) clearly show that during the first three minutes of solidification a columnar dendritic zone formed from the original upper cast surface, and an equi-axial dendritic zone formed from the original lower cast surface. Inverting the casting about its major axis caused columnar dendrites to form under the equi-axial dendrites thus brought to the top in one half of the casting, and equi-axial dendrites to form above the columnar dendrites in the other half of the casting. These facts suggest that if crystallites were falling from the upper portion of the still liquid castings, such crystallites were rapidly responding to the enforced change in direction of the gravitational influence. Since the difference in density between the liquid steel and the solid crystallites at the same temperature is known to be very small, figures of 7·1 and 7·3 g./c.c. having been experimentally observed by other workers, it follows, by an application of Stoke's Law, that the size of the falling crystallites must be greater than 0·2 mm. if the rate of sedimentation is to exceed 1 cm./sec. From the observed dendritic network structure of the crystals it appears that the crystal aggregates will initially have much liquid metal in their interstices, so that their bulk density will be still closer to that of the liquid, and the extent of aggregation will have to exceed 0·2 mm. for the rate of sedimentation to reach the value of 1 cm./sec.

Although little differences in composition between the various zones of this casting are observed, the two columnar zones show a greater hardness, and correspondingly higher yield points and ultimate tensile strengths. Comparison of the ductility values of the various zones was, to some extent, vitiated by the two abnormal fractures which occurred on the central portion of the casting which solidified after inversion.

The differences in the microstructure across the casting were slight, as will be seen from Fig. 23. The pearlite was more uniformly dispersed in the equi-axial zones, but in the segregated zone the pearlite was distributed in the form of discontinuous chains around the ferrite. The white line of demarcation, shown in the sulphur print, between the equi-axial and the columnar dendritic structures in the original lower cast surface could not be associated with any marked change in the microstructure.

DISCUSSION AND PROPOSALS FOR FUTURE WORK

In view of the great difference in properties and applications for carbon-steel castings over the range of 0·15 and 0·50% carbon content, to know that the mechanism of solidification does not appear to differ over this range of carbon content is of some value. The Committee regards it as highly important that work of this type should be extended to steel of higher carbon content, which would crystallize in the γ form and which would not, therefore, be subject to the peritectic transformation. Similarly, it is intended to extend this type of investigation to low alloy steel, not only because of the extended liquidus/solidus range of such steel, but also because of the higher mechanical properties which are attainable, and which are in increasing industrial demand.

Since the solidification of a liquid involves the liberation of heat, the solidification of a casting would be expected to proceed from the outer wall from which the heat is lost, and for pure metals solidification does proceed uniformly from the outer wall, as is demonstrated from the production of ' slush ' castings. For an alloy, however, the additional components provide additional degrees of freedom, in accordance with the phase rule, so that solidification takes place over a range of temperature, with corresponding differences in composition between the solid and liquid metal in contact together. For static conditions the initial formation of a solid outer rim of a carbon-steel casting leads to a local enrichment of the liquid steel in carbon and other elements, so that even at the same temperature further solidification would be easier within the bulk liquid rather than adjacent to the wall. Thus, although the formation of internal crystals is favoured (provided suitable initiating nuclei are present), their growth will be checked by the heat liberated, and a layer of impure liquid will be formed around them as a result of their growth. Motion of the crystallites would, therefore, be a factor favouring the rate of growth on the crystallites, which would thus come into contact with fresh liquid steel. Movement of the crystallites under gravitational influence is therefore a factor consistent with their growth to the observed crystal size. By similar reasoning it can be seen that crystallization from the outer wall and into fresh liquid steel is consistent with the columnar dendritic formation observed.

The fact that a higher mechanical strength has been recorded for the columnar dendritic zones is because of the difference in composition rather than structure. Further work is required upon the formation and the significance of the white line.

The design of these horizontal castings is such that convection of the liquid steel before solidification would not be expected to be important, and in this

respect, this work has confirmed the earlier conclusions of Mr. Basil Gray.* The same castings, if cast in the vertical position, might show a convective influence and a consequent worsening of the segregation. This point should be examined.

This work has confirmed that the control of the superheat of the liquid steel before casting is a major factor of importance, but since, in an industrial foundry, the degree of superheat is settled as a compromise between the needs of the different sectional thicknesses of the casting, further work is in hand to measure the effect of chill materials in terms of relative superheat, so that the desired rates of solidification may be controlled for all the various sections of a complex casting.

SUMMARY AND CONCLUSIONS

The following observations have been made in the course of a metallurgical examination of steel castings 18 in. long and 4 in. square, having a carbon content between 0·12 and 0·54%, cast horizontally into sand moulds with varying degrees of superheat up to 100° C. :

(1) The structure consists of three main zones, *viz.* : (*a*) Columnar crystals running from the upper cast surface to the thermal centre of the casting ; (*b*) nuclear crystals at low pouring temperatures, or columnar crystals at high pouring temperatures, running from the lower cast surface ; and (*c*) equi-axial crystals as an intermediate zone extending from the lower crystal formation up to the thermal centre. The depth of this zone is increased by high pouring temperatures. In addition, there is normally a segregate at the thermal centre of the casting, and often a light etching band at the junction of zones (*b*) and (*c*).

(2) The nuclear and equi-axial zones in the lower part of the casting are slightly lower in carbon, phosphorus, and sulphur contents than the columnar zones of the upper part. In the central segregate the contents of these elements is much higher, and the light etching band between zones (*b*) and (*c*) is lower in sulphur and phosphorus than the zones above and below it.

(3) In conformity with the differences in composition, the yield point, ultimate tensile strength, and hardness of the nuclear and equi-axial crystal zones are slightly lower than those of the columnar crystal zones.

(4) It is concluded that the finer structure in the lower half of each casting is caused by the crystallites falling during solidification. This conclusion is supported by an experiment in which a casting was inverted shortly after solidification had commenced. Equi-axial crystals formed and rested on the primary columnar crystals which were then at the bottom of the casting. It is also concluded that the formation of columnar dendrites is dependent upon the absence of crystal nuclei.

* *Journal of The Iron and Steel Institute*, 1944, vol. 150, No. II, pp. 5P–17P.

Observations at the Stockline in a Driving Blast-Furnace

A Technique for Determination of Contour, Movement, and Gas Composition

By E. W. Voice, B.Sc., A.Inst.P.

Introduction

DETAILED discussions and theories on furnace operation involve the knowledge of temperature, CO and CO_2 distribution across the stack, together with stockline contours and rates of burden descent at the stockline.

While there are many other furnace measurements that must be made in order to build up detailed theories on which to base blast-furnace operation, the exact knowledge of all the phenomena at the stockline will provide many valuable pointers. Model experiments devised to find the material distribution obtained with various bell and throat arrangements are very valuable and have been confirmed when filling static furnaces, but there is the possibility that other overriding influences in the furnace may cause the stockline to be modified on a driving furnace. Investigations have now been made on four furnaces, and the technique is as follows.

DESCRIPTION OF APPARATUS

Figure 1 shows a typical installation. A short horizontal pipe of 2 in. dia. is fitted through the brickwork of the furnace shell at a position above the stock and below the bell. A long pipe of $1\frac{1}{4}$ in. dia. is then threaded with a Bowden wire and this assembly is inserted and slides through the 2-in. pipe, a suitable weight having already been attached to the end of the wire inside the furnace. The weight, which is controlled by the wire outside, is lowered into the furnace. The long tube slides in and out, so that the depth of stock below the pipe may be obtained

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Mr. Voice is in the Field Trials Section of the Ironmaking Division of the Association.

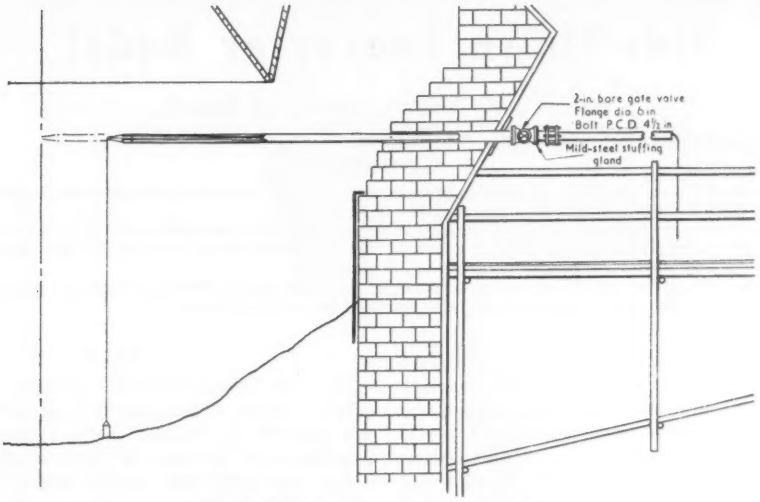


Fig. 1—Stockline contour apparatus

for various distances across the stack. A traverse can be obtained in 2 to 5 min., depending on the convenience of platforms, etc., and an accuracy of ± 3 in. should be attained.

With an adequate length of platform, there is no reason why the full diameter of the stack should not be traversed, but in practice usually only a radius of it is traversed. If the wire passes over a pulley fitted to the outer end of the long tube and returns to the furnace gallery, it is possible to manipulate the weight from a short platform, although the long platform makes the experiment much easier. With repetition of the traverse a few minutes later, the changes in position and shape of the contour give reliable figures of actual burden descent at different positions on the stockline. The tube is removed after an experiment and the 2-in. valve is closed.

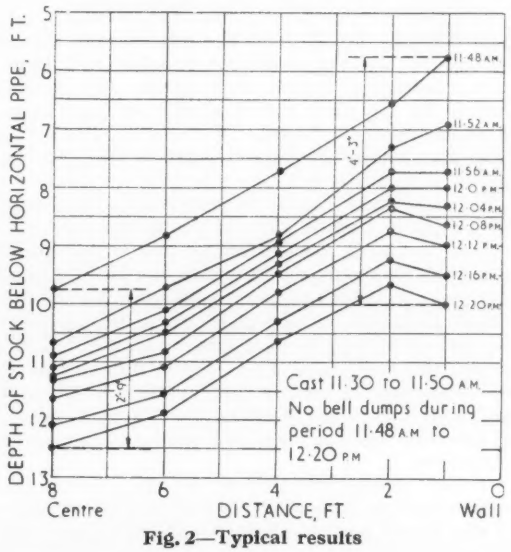


Fig. 2—Typical results

RESULTS

To obtain true stockline contours at any given instant, separate graphs are drawn for each tube position, plotting the depths obtained against the times, and by extrapolating or interpolating, the depths can be read off for each rod position at given times. A series of depths is read off, at 4 min. intervals, and for each given time the depths are plotted against the rod position, and graphs are drawn through points corresponding to identical times at each radial distance, giving results in the form of Fig. 2. This shows clearly that this furnace bell threw a **V** stockline, the furnace was driving fairly smoothly, and that the rate of descent of burden was greatest at the walls.

EXTENSION OF TECHNIQUE

By replacing the weighted Bowden wire with a weighted flexible tube, it is possible to take gas samples from the stockline, as well as to measure the rates of descent of the stockline and stockline contours as before.

An asbestos sealed metallic flexible tube is used for this purpose. Difficulties may be experienced due to the tube having a sharp bend inside the furnace, but these can be eased by fitting a short piece of very flexible metallic tube of $1\frac{1}{8}$ in. dia. to the long tube, or by using a long tube of larger diameter fitted with a pulley on the end inside the furnace.

A thermocouple could also be threaded through the flexible pipe to give gas temperatures at the stockline.

Acknowledgment

The work described above is part of the research programme of the Blast Furnace Process Committee of the British Iron and Steel Research Association.

Experiments on the Gas and Fluid Flow in a Side-Blown Converter Model

By M. P. Newby, B.Sc., A.Inst.P.

SYNOPSIS

In order to throw light on the movements of metal, slag, and blast, in a side-blown converter, experiments have been carried out on a small-scale model at room temperature.

The existence of a back eddy filling a large portion of the chamber has been demonstrated, and it is thought that the heavy wear on the lining, which occurs on the back wall above the tuyeres, may be associated with a recirculating stream of hot gas which strikes the wall in this region.

Plans for further research include similar experiments on converters of different designs and experiments on full-scale and small-scale converters under blowing conditions, with hot metal.

In the side-blown converter the blast has a twofold task: firstly to bring oxygen into intimate contact with the molten metal and cause oxidation of the carbon, silicon, and manganese, and secondly to stir the metal in the bath and ensure that the oxidation proceeds throughout the metallic mass. This stirring will occur partly by the direct action of blast and it may be intensified if a boil develops in the bath during the oxidation of the carbon. There is as yet no direct observation that a boil develops which is analogous to that occurring in the open-hearth furnace.

The refractory walls of the chamber in a converter are eroded by the moving metal, slag, and blast. Particles of ferrous oxide deposited on the walls cause softening of the surface, and the softened layer exposed to the drag of moving gas or liquid is worn away.[1, 2]

It is recognized that neither the metallurgical processes, nor the processes of refractory wear, can be fully understood without a knowledge of the fluid motions which occur within the chamber.

AIM OF THE EXPERIMENTS

Since, under conditions of actual operation, the motion of liquid and blast in a converter cannot be studied in detail, it was decided to build a laboratory model in which the type of flow could be observed. Such models, although not able to give an exact representation of the flow which occurs in practice, nevertheless give a very valuable picture of the general flow patterns and are a powerful stimulus to thought.

Initially, the experiments were carried out to discover if there was any relation between the flow of the metal and blast within the chamber and the erosion of the refractory lining above the metal. Attention has thus been confined to the form of the liquid surface and the type of flow occurring in the blast. Investigations of the motion in the body of the liquid are now also proceeding and will be reported later.

Paper SC/CA/46/48 of the Side-Blown Converter Refractories Sub-Committee of the Foundry Moulding Materials and Refractories Committee of the Steel Castings Division of the British Iron and Steel Research Association, received 23rd December, 1948. The views expressed are the author's and are not necessarily endorsed by the Sub-Committee as a body.

Mr. Newby is at the Physics Laboratories of the British Iron and Steel Research Association.

THEORY

The side-blown converter presents a very complicated system of gaseous and liquid flow, and it is not possible to build a perfect model with a full application of the laws of physical similarity. In an actual converter the molten metal is accompanied by a small proportion of slag, but to a first approximation the form of the fluid will be similar to that of a bath containing metal only. The first stage of the work, therefore, was to consider a model containing a single liquid which corresponds to the metal. These experiments were carried out on a $\frac{1}{8}$-scale transparent model, blown with air, and employing water or mercury as the working liquid. The temperature increment, which occurs in practice when the blast strikes the bath, could not be simulated.

Consideration of the dynamic forces acting in the system leads to the result that similarity of flow between a model and the full scale, under these limitations, requires the simultaneous equality of four independent pairs of parameters.

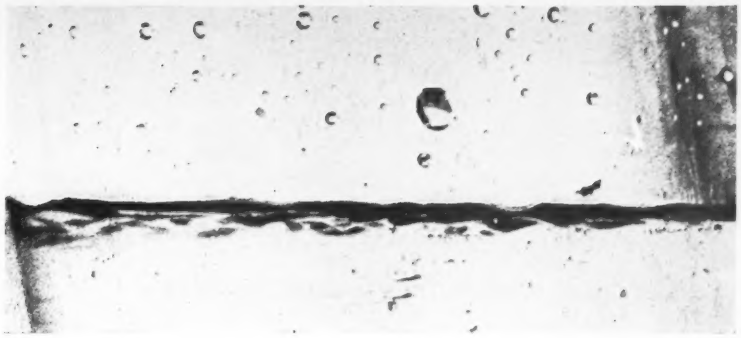
From a physical point of view these parameters are best represented by two Reynolds numbers and two Froude numbers and are given symmetrically by:

$$\frac{V_G \rho_G}{\nu_G}, \quad \frac{\rho_G V_G^2}{(\rho_L - \rho_G) lg}, \quad \frac{\rho_L V_L^2}{(\rho_L - \rho_G) lg}, \quad \frac{V_L \rho_L}{\nu_L}$$

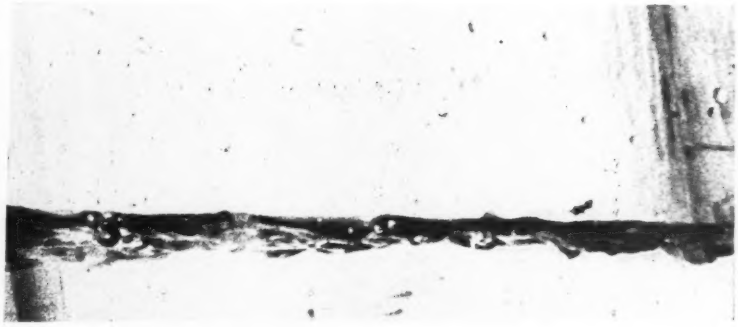
denoted by R_G, F_G, F_L, and R_L, respectively, where V_L, ρ_L, ν_L are the velocity, density, and kinematic viscosity of liquid, respectively, with similar symbols for the gas.[3] For similarity we must have, simultaneously, $R_G = R'_G$, $F_G = F'_G$, $F_L = F'_L$, $R_L = R'_L$, where the dashed symbols refer to the model.

The experiments to be described later show that the motion of both liquid and gas in the converter model is turbulent, despite the fact that in the experiments the Reynolds number was less than obtains in practice. Under turbulent conditions, it is known that flow patterns change little over a wide range of Reynolds numbers, so that exact fulfilment of the criteria $R_G = R'_G$ and $R_L = R'_L$ is not necessary. Thus the shape of the free liquid surface is the most important factor in determining the general nature of the flow once geometrical similarity has been established.

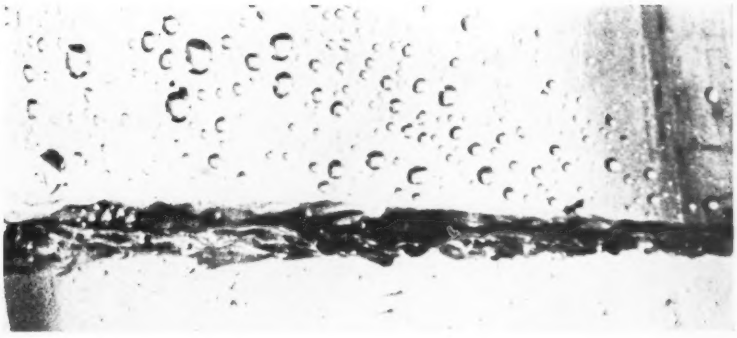
It may be expected that by far the greatest disturbance of the surface is caused by the direct impact of the blasts, and to obtain similarity of this dis-



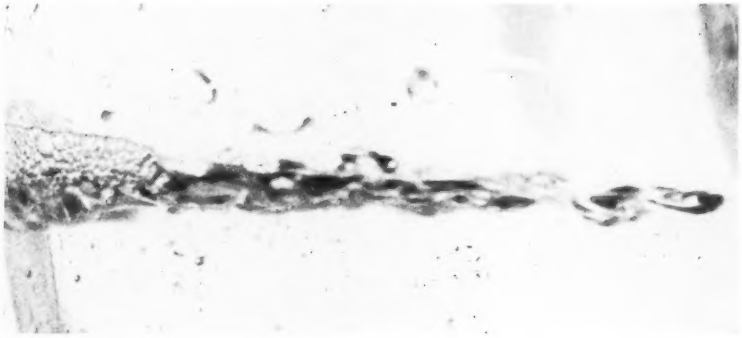
(*a*) Air pressure 0·5 in. in W.G. (1250 cu. ft./min.)



(*b*) Air pressure 1·0 in. W.G. (1770 cu. ft./min.)



(*c*) Air pressure 2·0 in. W.G. (2500 cu. ft./min.)



(*d*) Air pressure 3·0 in. W.G. (3300 cu. ft./min.)

Fig. 1—Disturbance of water in side-blown converter model, with varying air pressures (behind tuyeres); corresponding full-scale air flows are given in parenthesis. The tuyeres are on the right and above the liquid surface

[*Newby*

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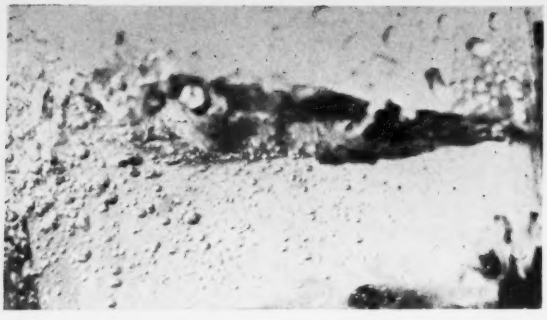
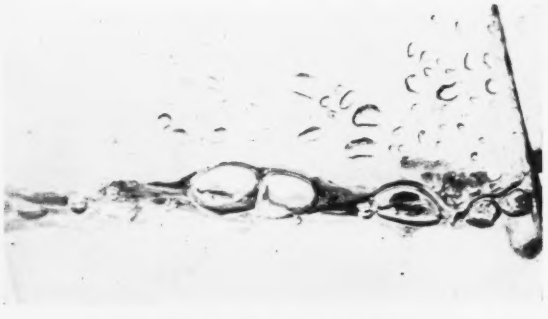
(*a*) Mercury; air pressure 6·75 in. W.G. (1250 cu. ft./min.)



(*b*) Water; air pressure 6·75 in. W.G. (4600 cu. ft./min.)

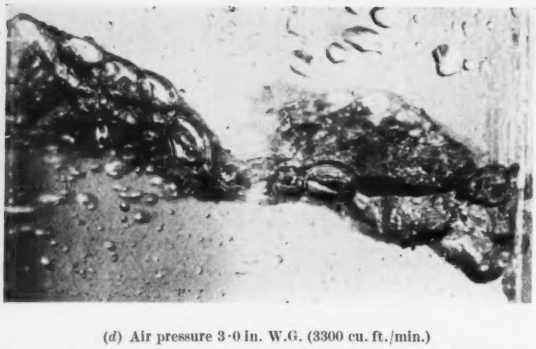
Fig. 2—Disturbance of fluid (mercury or water) in side-blown converter model, with varying air pressures (behind tuyeres); corresponding full-scale air flows are given in parenthesis. The tuyeres are on the right and above the liquid surface

(*a*) Air pressure 0·5 in. W.G. (1250 cu. ft./min.)



(*b*) Air pressure 1·0 in. W.G. (1770 cu. ft./min.)

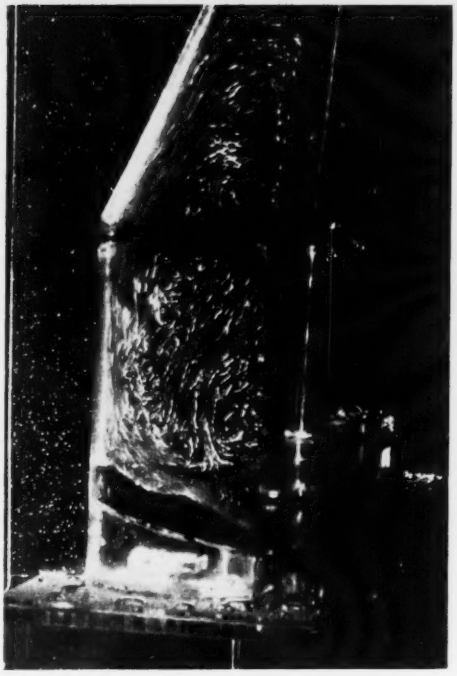
(*c*) Air pressure 2·0 in. W.G. (2500 cu. ft./min.)



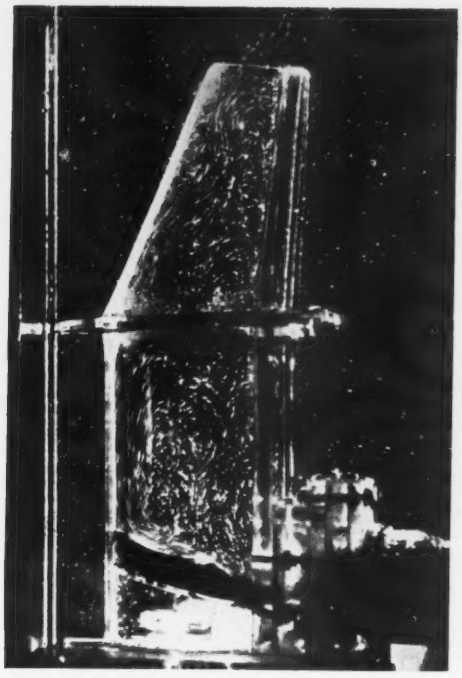
(*d*) Air pressure 3·0 in. W.G. (3300 cu. ft./min.)

Fig. 3—Disturbance of water surface in side-blown converter model, with varying air pressures (behind tuyeres); corresponding full-scale air flows are given in parenthesis. The tuyeres are on the right and were just below the undisturbed liquid surface before blowing

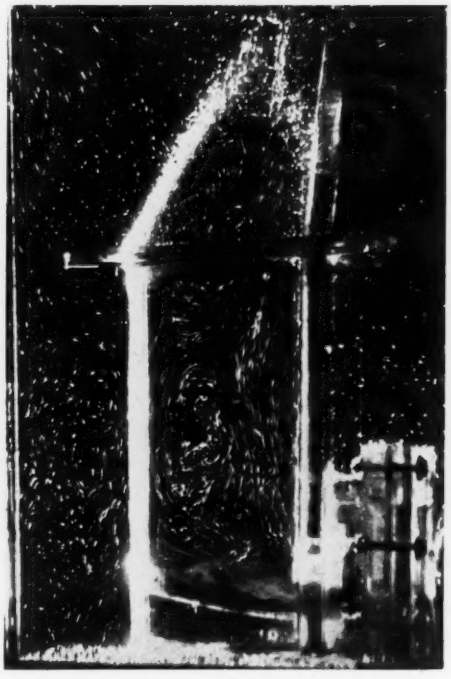
Fig. 4—Splash of liquid in converter model



(*a*) Plane AA



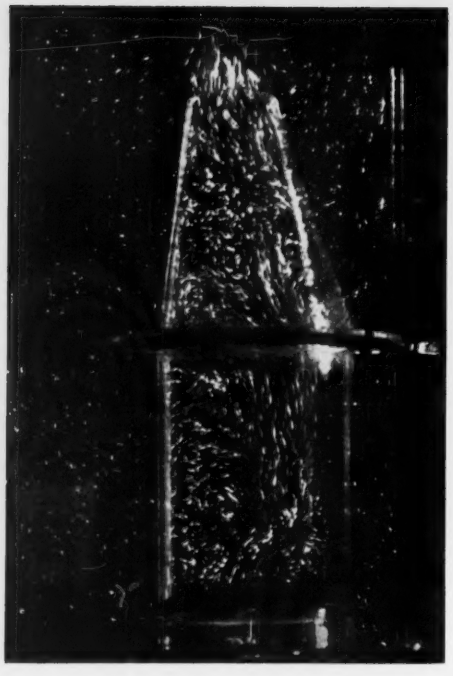
(*b*) Plane AA



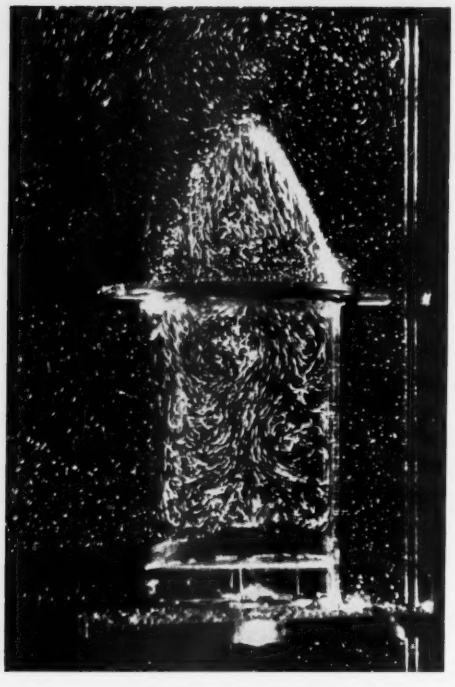
(*c*) Plane BB

(*d*) Plane BB

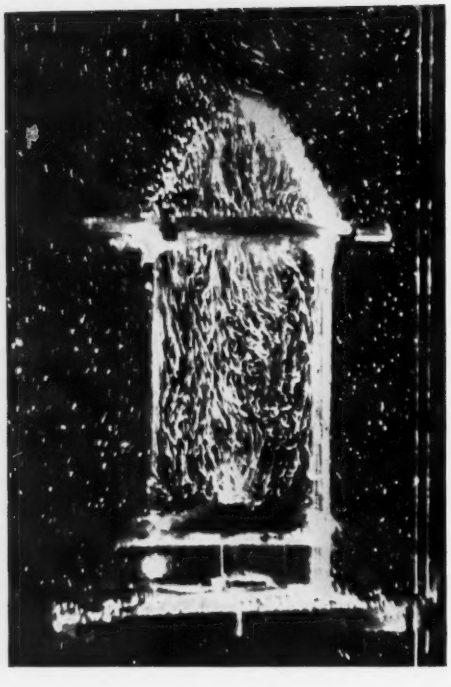
Fig. 5 (a to d)—Photographs of the patterns of flow in converter model through various planes (see Fig. 8)



(*e*) Plane GG



(*f*) Plane DD



(*g*) Plane EE

Fig. 5 (e to f)—Photographs of the patterns of flow in converter model through various planes (see Fig. 8)

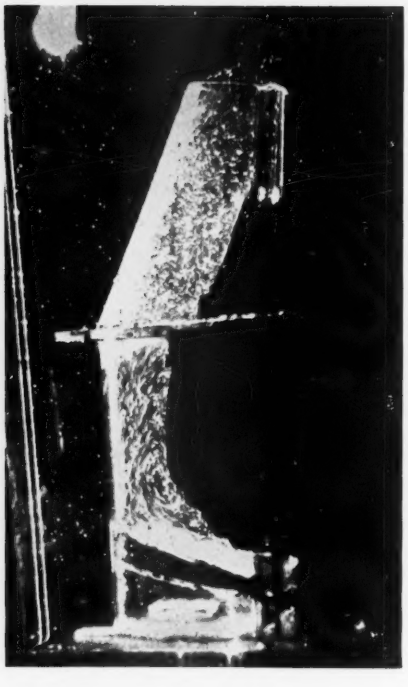


Fig. 6—Flow in converter model with a modified back wall

turbance, between converter and model, it is necessary to satisfy the relation $F_G = F'_G$. This ensures that the dynamic forces in the impinging jets bear the same ratio to the gravitational forces on the free surface, in both model and full-scale systems.

Observation of a model shows that the liquid flow consists of a shallow fast-moving surface layer, together with a relatively slow circulation of the bulk of the liquid. In the absence of rapid movements of large volumes of liquid no large-scale movements of the surface occur. Only ripples are caused by the fast-moving surface layer of the liquid and an elevation of its surface where this layer strikes the front wall. When $F_G = F'_G$ this elevation is not so great as the depression caused by the initial impact of the jets. These considerations mean that equality between F'_L and F_L, in model and converter, is less important than equality between F'_G and F_G. The first studies on the model were therefore made with $F_G = F'_G$, the other criteria not being satisfied.

A correction to the modified Froude numbers must be made to account for surface tension. The effect of this is to cause an apparent increase in the gravitational acceleration, so far as disturbances of the liquid surface are concerned. This amounts to about 2–3% for the larger deformations of the surface in the model but will be only about $\frac{1}{20}$ of this amount in the full-scale converter. Even in the model, therefore, the major deformations of the surface will not be greatly affected by surface tension. However, small disturbances of the surface having high curvature, and droplets detached from the surface, will give much larger pressures because of surface tension, and the model will not give a true representation of the surface of the metal for these small displacements.

EXPERIMENTAL WORK

Disturbance of Liquid Surface

The experimental work was carried out in two stages : (i) To determine the type of surface disturbance in a model when $F'_G = F_G$, and (ii) to determine the form of the gas flow above the liquid.

To achieve the first stage a $\frac{1}{8}$-scale transparent model of a typical side-blown converter was built. The converter was plant *B* of the " First Report of the Side-Blown Converter Practice Sub-Committee."[4] It has five tuyeres 1·5 in. in dia., and the blower has a maximum delivery of 2500 cu. ft./min. Air was used for producing the blasts in the model, and various liquids were employed to simulate the steel. The most important was water, but mercury was also used.

Figures 1*a*–1*d* show the disturbance of the water caused by the air jets impinging on the surface under conditions of $F'_G = F_G$. These correspond to full-scale blast rates of 1250, 1770, 2500, and 3300 cu. ft./min., respectively. The pressures behind the tuyeres in the model were 0·5, 1·0, 2·0, and 3·0 in. W.G., respectively.

A similar experiment with $F'_G = F_G$ was carried out with mercury instead of water, and the resulting disturbance is shown in Fig. 2*a*. The pressure behind the tuyeres was 6·75 in. W.G., corresponding to a full-scale blast rate of 1250 cu. ft./min. Figure 2*b* shows the much greater displacement obtained using water at the same pressure and corresponding to a blast of 4600 cu. ft./min. The blowing angle in all these experiments was $12\frac{1}{2}°$.

With $F'_G = F_G$ the Reynolds number in the model tuyeres is 4400 with water, and 16,300 with mercury. These are much lower than the corresponding Reynolds number of 250,000 in the full-scale converter. However, the numbers are above the critical value and they indicate that the gas flow in both converter and model is turbulent.

The form of the disturbance of both mercury and water was nearly identical, although at room temperature the kinematic viscosity of water is nine times greater than that of mercury. This confirms the conclusion that $R'_L = R_L$ is not of the greatest importance in determining the shape of the liquid surface for a model. Indeed, it was only when a highly viscous paraffin was used in the model that the surface pattern was noticeably altered. Very little liquid is removed from the surface merely by the impact of the blast, and the drops of water on the walls (as shown in Fig. 1*c*) represent an accumulation taking place over many minutes.

It must be emphasized that the series of photographs given in Fig. 1 shows the displacement of the liquid when the tuyeres are above the surface. If the liquid is allowed to rise just above the tuyeres, the disturbance is much greater and less regular. Figures 3*a*–3*d* show the effect of blowing in this manner with the same blast pressures as in Fig. 1. The liquid is thrown in all directions from the tuyeres, and some of it strikes the back wall above the tuyeres. Flow of this type has not been considered further in the present series of experiments ; it would almost certainly produce conditions of heavy wear in the region of the tuyeres if allowed to occur in practice.

Since $F'_G = F_G$ was found to be the most important criterion to be satisfied for studying the liquid surface, the experiment was repeated using two liquids, one corresponding to the metal and the other to the slag. Owing to the fact that the density of the liquid is much greater than that of the air, the parameters F_G and F_L may be simplified to $\rho_G V^2_G/\rho_L lg$ and V^2_L/lg respectively. Thus, F_L in this form is independent of density, and is in fact the ordinary Froude number. Let the density of the slag be ρ_S; then $\rho_L/\rho_S = \rho'_L/\rho'_S$. For similarity of surface pattern $F'_G = F_G$, that is :

$$\rho'_G V'^2_G/\rho'_L l'g = \rho_G V^2_G/\rho_L lg$$

$$\therefore \quad \rho'_G V'^2_G/\rho'_S l'g = \rho_G V^2_G/\rho_S lg$$

$$\text{or} \quad F'_S = F_S$$

A concentrated aqueous potassium iodide solution with a layer of paraffin on top gave a density ratio of approximately 2 : 1, which is about the ratio of densities of metal to slag. Under these conditions physical similarity due to jet impact was achieved for both metal and slag. The amount of slag is small in proportion to the steel, and it was found that the lighter liquid tended to form into two pools on either side of the area where the blast strikes the surface. Apart from this feature the surface was similar in outline to that of a single liquid.

To provide the conditions of a boil in practice, an

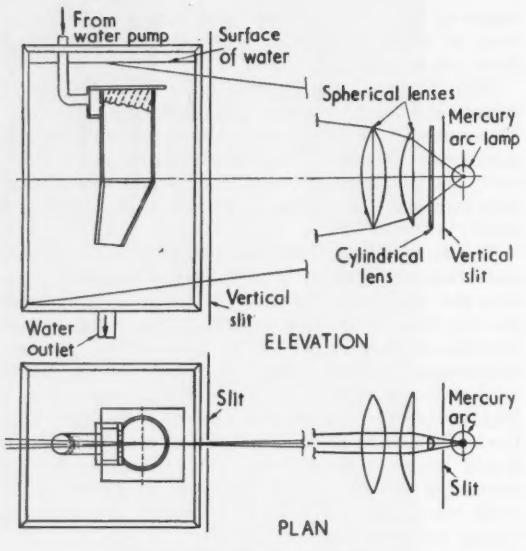


Fig 7—Sketch of apparatus

experiment was carried out in which air was injected through 36 holes drilled in the bottom of the converter. The maximum quantity of air passed through the holes was calculated on the basis that the maximum boil would occur if all the carbon monoxide were liberated from below the liquid surface. The boil tended to destroy any regularity of pattern on the liquid surface and increased the amount of liquid picked up in the form of droplets. Figure 4 shows the converter being blown under these conditions, with a considerable amount of liquid being carried up about half-way to the nose, and a small amount actually leaving the converter. It is difficult, however, to compare this pick-up in the model with that to be expected in a full-scale converter, as the sizes of the particles in the two cases cannot be compared (*see* discussion on surface tension, p. 453).

Conclusions from Experiment on Liquid Surface

The most important conclusion from this part of the work is that the disturbance of the steel surface caused by the direct impact of the blasts is small, and it would amount only to a vertical displacement of a few inches in the real converter when the blowing angle was $12\frac{1}{2}°$ and the full-scale blast rate was 1770 cu. ft./min. The material picked up from the liquid and carried up into the converter is probably composed largely of material thrown from the surface by the boil and caught up in the blast.

Flow of Gases

From this point the research was continued using a different technique so as to study the flow of gases above the steel surface. Plasticene was used instead of water or mercury to simulate the steel surface, and it was moulded to the general shape of the surface as determined from the first part of the experiment. Water, instead of air, was then pumped through the tuyeres. This technique was adopted for two reasons : firstly, for a given Reynolds number in the converter chamber the velocities with water are only about $\frac{1}{12}$ of those with air ; and secondly, it is easier to make the flow of water visible by introducing particles into the stream.

In these experiments the Reynolds number in the main body of the converter was made the same as in the full-scale system, *i.e.*, about 16,000. Owing to the expansion of the blast which occurs in a converter, it was not possible to obtain Reynolds similarity at all points of the system. True geometric similarity was sacrificed by making the areas of the tuyeres five times too great to allow for the fivefold expansion which occurs in the blast when heated. In this way the jets emerging from the tuyeres were 2·24 times greater in diameter than they should have been for true similarity, but they possessed the correct velocity. From the point of impact with the liquid the streams should have approximately the correct dimensions in relation to the main chamber.

Small bubbles were used to make the flow of the water visible. In the first experiments air was sucked into the water-pump supply line through a needle valve, and was broken into small bubbles in its passage through the pump. Later a better control of the bubbles was obtained by injecting a small amount of air through a capillary tube passing through the base of the model. The tube was placed so that its end projected into one of the streams of water from the tuyeres. This caused the water to be broken up into small bubbles which followed the flow inside the chamber.

An intense beam of light in the form of a sheet about $\frac{1}{8}$ in. thick was used to illuminate the flow. This was obtained by means of a 500-watt compact-source mercury arc lamp. Light from the arc was focused into an approximately parallel-sided sheet by means of a combination of cylindrical and spherical lenses followed by a slit. The sheet of light obtained by this method enabled any plane through the converter to be illuminated at will, and the components of fluid flow in this plane could then be determined from photographs of bubble tracks. Figure 7 shows the layout of the apparatus.

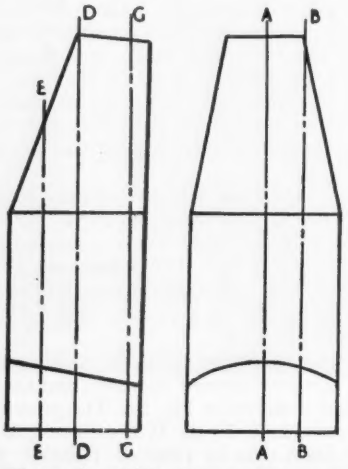


Fig. 8—Planes in which photographs were taken

Total reflection of the light from the bubble surfaces was obtained in a direction making about 105° with the incident beam, and convenient track lengths on the photographs were obtained by exposure times of $\frac{1}{50}$ and $\frac{1}{100}$ sec. Owing to the alternating character of the arc, each bubble appears as a series of short streaks, and the distances between these are directly proportional to the component of fluid velocity in the plane of illumination.

In order to make the construction easier, the converter was built upside down and completely immersed in a glass-sided tank. This had the double advantage of making it unnecessary to construct a watertight connection to the top of the converter and of allowing the water from the nose of the converter to discharge into a large volume, thus simulating actual conditions of operation. As there are no buoyancy forces in the model, its operation is unaffected by being inverted. The glass-sided tank was necessary to prevent optical distortion due to the curved sides of the model.

Results of Experiments on Gas Flow

Figure 8 shows the planes in which photographs have been taken, and Figs. *5a–5g* show typical photographs of the flow in these planes. From photographs such as these, together with visual observations, it has been possible to picture the flow in the chamber as a whole. This is illustrated schematically in Fig. 9.

The blasts from the tuyeres impinge on the metal surface and strike the front wall of the converter; they then proceed to spread over the walls. The greater part of the stream consists of a flow straight up the front wall and out at the nose. However, about one-third down the conical section there is a stagnant region on the back wall, and the upward-flowing stream divides in two; one of these is the stream which leaves the converter, and the other is a stream which flows down the back wall towards the tuyeres. Figure *5a* shows the stagnant region near the top and the stream flowing downwards from this point.

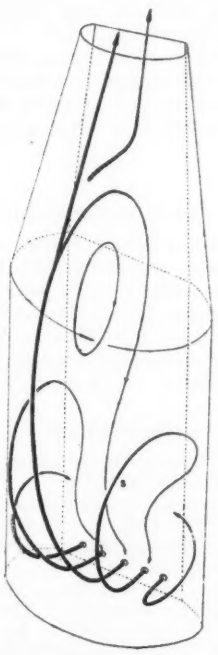


Fig. 9—Mean flow in converter as given by model

Other streams from the tuyeres spread along the walls at oblique angles and also converge towards the back wall above the tuyeres. The extreme flow lines in this instance proceed almost parallel to the steel along the side walls and approach the downward-flowing stream above the tuyeres almost at right-angles. The result of this 'pinching,' which can be seen in Fig. *5f*, is to force the downward stream into the centre of the converter and to cause fairly stagnant regions at the back at about one-third of the distance from the tuyeres to the point where the nose joins the main body of the converter. After having been forced into the centre of the chamber, the downward-flowing stream spreads out again in all directions (this may also be seen in Fig. *5f*). The result is that some gas actually flows backwards from the centre of the chamber towards the tuyeres in a direction almost opposite to that of the ingoing blast. Figures *5a* and *5b* both show this, although Fig. *5b* was taken when the backflow as a whole was temporarily weak. This gas stream moving towards the tuyeres is turned suddenly forward again as it approaches the blast from the tuyeres. Figure *5e* shows that the downward-flowing stream near the back wall was not quite symmetrical, presumably owing to some slight lack of symmetry in the construction of the model. This effect, however, does not appear in the parallel planes shown in Figs. *5f* and *5g*.

The flow is, of course, turbulent, and the details of the flow pattern are continually fluctuating about the mean pattern just described. This is particularly true of the back flow where, in particular, the position of the stagnant zone above the tuyeres is frequently changing. It is rather higher in Fig. *5a* than in Fig. *5b*.

Experiments have been carried out with equivalent tilt on the converter at 5°, 12½°, and 35°. The broad flow pattern was found to be similar in all these cases. Figures *5a–5g* show a model with an equivalent tilt of 5°. As was expected, the general flow pattern does not change with the flow rate.

In addition to the enlarged tuyeres which were used to compensate for the expansion of the gas, tuyeres of the correct geometrical size were also used, and the same amount of water was passed through. Again the flow pattern was of the same type. The diameters of both sets of tuyeres were small, compared with the overall dimensions of the chambers, and it is evidently the proportions of the chamber which are of major importance in controlling the flow of blast after impact with the metal. Likewise, the disturbances of the metal surface, as determined from the first part of the experiment, seem to be sufficiently small to have little effect upon the main gaseous flow pattern, and changes of the surface, such as must be occurring continually if there is a boil, will not be large enough to cause major changes in the flow of the blast.

Buoyancy forces do not exist in the model and have not been considered theoretically so far. From the general gas flow pattern, as now deduced from the experiment, the effect of buoyancy is likely to be small. It is only in the slower-moving back flow that large differences of temperature could produce buoyancy forces comparable with the dynamic forces. The gases composing this back flow, however, have traversed a long path inside the converter chamber and are likely to be uniformly heated to a high temperature. Significant buoyancy forces are thus unlikely to occur at any point of the converter chamber, and the lack of buoyancy forces in the model is unlikely to cause appreciable error in the determination of the gas flow pattern.

An endeavour was made to eliminate the downward-flowing current by reducing the distance between front and back walls. It was found, however, that only when this distance was reduced to about one-fifth of its normal value was the flow from nose to tuyeres prevented, and even then a small eddy formed just above the steel. Figure 6 shows this.

DISCUSSION

When a blast of air is blown into a chamber so as to form a turbulent jet, it is inevitable that a recirculation of some of the air will occur within the chamber. This is caused by the entrainment of the surrounding air by the jet followed by a back flow of air to take its place. Changes of design therefore may alter the form of the back eddy but will not eliminate it so long as turbulent blast jets are formed, and in the side-blown converter it is necessary to have these compact jets of air.

The full effect of the hot-gas recirculation is not known and cannot be determined from experiments of the type described here ; however, some correlation appears to exist between the flow pattern and the erosion of the refractory lining.

Examples of actual converters[5] show that erosion is heavy on the tuyeres, on the back wall immediately above them, and on the front wall above liquid level. The fast forward-flowing blast, with the particles picked up by it from the metal and slag surfaces, will account for the erosion which occurs opposite the tuyeres. In contrast to this, erosion above the tuyeres takes place in the region where the backward flow is occurring and where the mean velocities are probably no more than $\frac{1}{10}$ of those occurring near the front wall. However, the conditions in this stream are such as to enable it still to erode effectively due either to high temperature or to the constitution of the suspended particles. In particular, above the tuyeres, where the recirculating current flows backward and is then suddenly turned forward again by the incoming blast, there will be a tendency to throw suspended slag particles and splashes on to the lining. This, combined with a relatively high velocity in the backward-flowing stream at this point, with consequent higher drag on the refractory surface, will form a region susceptible to erosion.

CONCLUSIONS AND FURTHER SUGGESTIONS

It appears that the recirculating stream of hot gas inside a converter has great powers of erosion, in spite of its relatively low velocity compared with the ingoing blast velocity. It would appear to be an advantage in design to minimize the area of surface in contact with this recirculating stream.

One possible solution of the problem is to make the flow of the blast take on a helical form after it has struck the metal. A vortex of this nature with a vertical axis could be obtained by placing the tuyeres in two groups diametrically opposite and directing them at points on opposite sides of the centre of the chamber. The degree of spin will depend on the points at which the blasts are directed.

Preliminary experiments with a model of this type have shown that the back eddy is now confined to a stream flowing down the centre of the chamber from the nose. This stream does not come in contact with the walls at any point. It is found that a certain amount of air is drawn in from the outside atmosphere and this may be an advantage in keeping the top of the chamber cool.

Another possibility is to make the back wall of the converter bulge outwards above the tuyeres so that the recirculating stream may approach the jets without undergoing so violent a change of direction at the point of entry to the jets.

A final suggestion is that air introduced at low velocity through a set of large tuyeres on the back wall, well above the normal tuyeres, would mix with the downward-flowing stream and cool it and thus make it less liable to cause erosion. In further research to be carried out it is intended to experiment on several such modified designs. It is also intended that the work begun on a model at room temperature shall be continued with a small converter containing molten metal, which will give a much closer similarity to the dynamic, thermal, and chemical processes existing in actual operation.

A periscope is under construction with which experiments are to be carried out on a full-scale converter. This should be particularly useful in determining the type of agitation which occurs in the bath during blowing.

Acknowledgments

The author wishes to thank Miss J. D. Tyler and Mr. S. E. McEwen, who assisted in the construction of the apparatus ; Mr. L. E. Eaton and Mr. R. J. Hayes, who took the photographs of the disturbances of the liquid surface ; and Mr. J. A. Leys, who took the photographs of the bubble trajectories.

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Experiments on Gaseous Mixing in Open-Hearth Furnace Models

By R. D. Collins, B.Sc., and J. D. Tyler

Part I—MAERZ

SYNOPSIS

A technique using models is applied to some designs of producer-gas-fired open-hearth furnaces. Useful results may be obtained from a model working at room temperature, in spite of the neglect of secondary processes, of which the buoyancy and expansion of the furnace gases are the most important.

Carbon dioxide is used as a tracer, and concentrations measured by means of an infra-red gas analyser determine the degree of mixing achieved in the combustion zone of several designs. A mixing index is adopted to facilitate comparison. The designs tested are essentially of the Maerz type, but one semi-Venturi type is included as a comparison. The use of a central air port, similar to that tested by Allen, Cook, and Fenton, shows a considerable improvement on the conventional design as regards mixing.

Introduction

Practical Problem

THE problem of predicting the behaviour of a furnace from a knowledge of its design and operating conditions is one of great complexity. To a considerable extent it may be broken down into two problems: one of heat flow in which gas velocities and rates of heat liberation in the flame are assumed known, and one of gas flow in which a temperature distribution is similarly assumed. These two problems are highly interdependent, the variables determined in each case being the given constants in the other. A third problem, that of determining refining behaviour, given the heat flow, is more easily separable except in so far as the chemical heat of reaction of the bath enters into the heat-flow equations.

It is possible to tackle these problems either together or separately. An example of the first method was the set of trials reported in *Special Report No.* 37.[1] In these trials, three working furnaces were provided with instruments to measure as many as possible of the quantities relevant to the determination of heat flow and gas flow, and refining characteristics. The results were analysed statistically. The main disadvantage of this method is the amount of work involved in collecting data for each furnace, which severely limits the number that can be dealt with; also no work can be done on a design until at least one furnace has been built to it. On the other hand, it has the great advantage that the minimum of theoretical assumptions need be made.

In the report quoted, one of the main conclusions was that flames were too long, so that a higher rate of heat transfer to the bath should be attained by improving the mixing of the gas and air so as to shorten the flame. This could be done by an increase of gas velocity or an alteration in the shape or position of the gas and air ports. A practical difficulty in the way of increased gas velocity is the limited pressure gradient which brickwork will hold. Accordingly, work was done to determine the extent to which improvement in the design of ports and uptakes would enable gas-port velocities to be raised without increasing uptake pressure. The results[2] showed that the increase obtained in this way was not large. Work by the Steelmaking Division of B.I.S.R.A., on a model furnace run at moderate temperatures, has been directed to the effect of furnace end design on heat transfer to the hearth.[3] By bringing the air into the combustion chamber of the furnace through a central uptake (so that the incoming gas has to be 'cut through' the entering air) considerable improvements in performance, compared with furnaces in which the air enters through two side uptakes, can be obtained. This type of construction is specially useful where it is not possible to work with the high gas pressures required to give a high incoming-gas velocity.

Since these designs were intended to ensure rapid mixing, it was suggested that an experiment should be made to determine the mixing patterns of these and other furnaces directly. The work now reported is the result.

Theory of Method

Rummel[4] has shown on theoretical grounds, and has verified experimentally, that the combustion conditions of a furnace may be deduced from a study of a model at room temperature. The temperature at which the preheated gas and air are blown into an open hearth is so high that chemical reaction is almost instantaneous once the gases are in intimate mixture. Of the two processes of mixture—molecular diffusion and turbulent diffusion—the first is so slow, except over very short distances, that its effect is swamped by the second.

The gases enter the furnace with a momentum acquired in the ports and mix by turbulent diffusion. Once they are mixed, molecular diffusion ensures that the molecules come into collision, and reaction takes place immediately. By investigating the rate of mixing in a model, the rate of burning in a furnace can be determined.

In the present experiments, air at room temperature is blown through a model, and samples are taken

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Mr. Collins and Miss Tyler are in the Aerodynamics Section of the Physics Department of the British Iron and Steel Research Association.

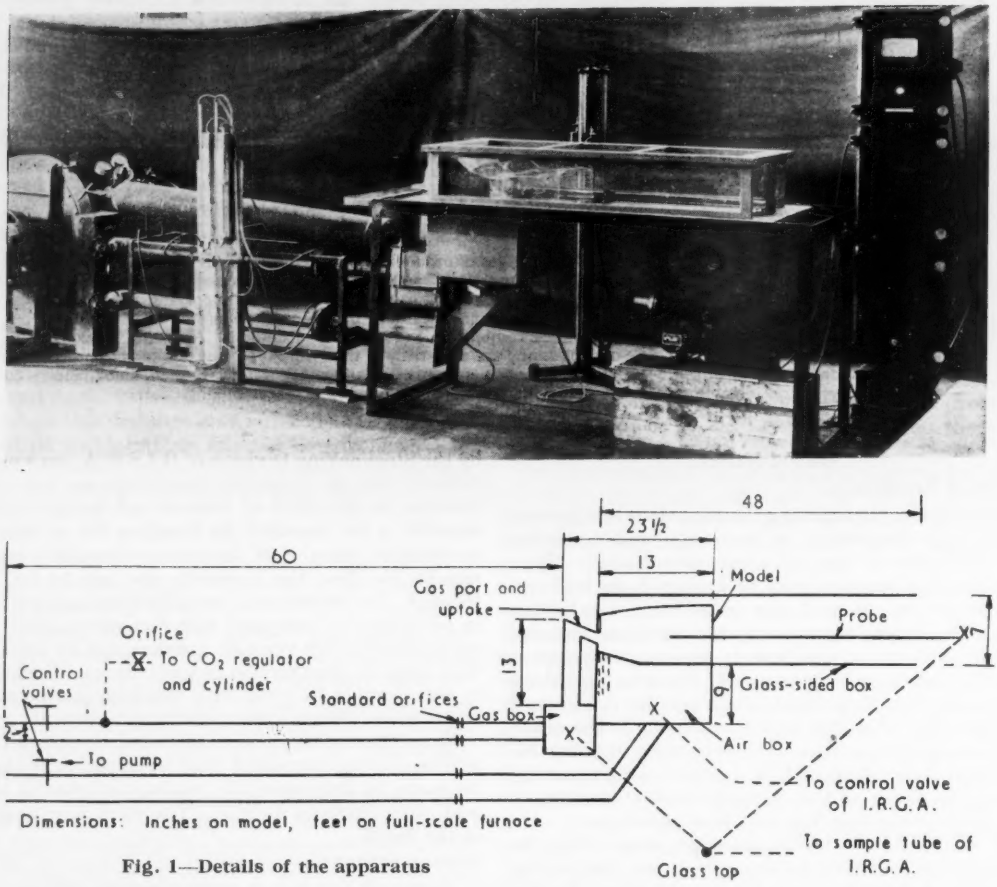

Fig. 1—Details of the apparatus

from various positions and examined to determine what proportion of the sample originated in the gas port, and what proportion in the air port, by means of a tracer method.

Approximations

The effects of scale change and the lower kinematic viscosity of air at room temperature, are balanced by adjustment of the flow rates, according to Reynold's criterion. It is well known that systems in which fluids move under the action of inertia and viscosity alone have geometrically similar flow patterns, provided that the boundary conditions are similar and that Reynold's criterion is maintained. Reynold's criterion, R, is equal to $V.l/\nu$, where V, l, and ν, are respectively velocity, scale unit, and kinematic viscosity. All these quantities are determined in both model and furnace (once the scale and model fluid have been chosen), except the velocities in the model; the model velocity is then chosen to satisfy the equation :

$$R_{\text{model}} = R_{\text{furnace}}$$

In the model the forces of inertia and viscosity are the only ones acting, so that its behaviour corresponds accurately to that of a full-scale furnace in which preheated air and gas are blown through the ports at the rates used in practice, but in which the gas and air have the same density, generate no heat on combination and, therefore, do not expand. Conditions in a furnace differ from this, firstly in that the gas is less dense than the air at the same temperature. This effect is small, the ratio of densities being 0·9 : 1 for the same preheat. In fact, a difference of 150° C. in preheat temperature can destroy the effect. Secondly, the burnt gas produced by the flame differs in density from both the unburnt air and gas. At the same temperature its density would be greater by 10% than that of its constituents, but owing to its higher temperature the flame has a positive buoyancy which tends to lift it towards the roof. An estimate of the magnitude of the modification to the flow pattern produced by this buoyancy can be made by comparing the buoyancy pressure of a 7-ft. column of gas at 1900° C., surrounded by gas at 1600° C., with the dynamic head of gas entering the furnace at 90 ft./sec. and 1100° C. The latter pressure is 0·34 in. W.G. and the former 0·002, a ratio of 170 : 1. The flow system due to the smaller pressure will have little effect except where velocities are low ; the further from the incoming end the greater will be the effects.

Another serious thermal effect is the expansion of the hot gases[4] which will alter the pattern of flow

since the gas forming the flame will occupy more space in the furnace than in the model. If the rise in temperature is from 1100° to 1800° C., with no change in momentum, then the linear expansion in both the height and the width of the flame is 20%. The temperature, and so the expansion at any point, will depend on the amount of heat liberated and on the heat radiated to the brickwork and bath. For this reason it is not possible to make an accurate allowance for it.

It is partly because of these differences in the behaviour of a model from that of a furnace that attention has been concentrated in these experiments on the part of the furnace nearest the incoming end, which is fortunately also the part most important in affecting flame length. Here, the flame has its highest velocity, and buoyancy systems have had least time to develop. For this reason, too, the study of single changes in otherwise similar furnaces has been the main object of the experiment, for the difference observed between two models that are similar except in one respect will be a more accurate representation of the difference between the corresponding furnaces, than either model is of its own furnace. Nevertheless, comparison of the results obtained in these models with the behaviour of the furnaces on which they are based, shows at least qualitative agreement.

DESCRIPTION OF APPARATUS

General Description

A fan supplies air to two pipe lines, each having a control valve and a standard orifice suitably placed. The lines are connected by flexible hose, one to the air box and one to the gas box on the model (Fig. 1). Uptakes and ports connect these to the furnace chamber. The flow rates are measured by manometers connected across the standard orifices. A small quantity of CO_2 is introduced into the gas-port line after the control valve to act as a tracer. The cylinder and regulator provide a steady flow which is checked by an orifice and manometer.

Samples drawn from predetermined positions in the furnace chamber are analysed for CO_2 concentration by means of an infra-red gas analyser. In this instrument the difference in CO_2 concentration in the sample and control tubes is read from an electrical meter. At high sensitivity its response, as shown by the calibration chart provided by the makers, is almost linear. The sensitivity is approximately 0·03% full-scale deflection, and with the aspiration rate used a steady reading is obtained in about 15 sec.

One end of each tube is connected to the suction side of a small air pump. The other end of the control tube is connected to a tapping on the air box. The sample tube is joined to a two-way stopcock, enabling it to draw air either from the sampling probe or from the gas box. In use, the apparatus is adjusted to give a zero reading when no CO_2 is coming from the cylinder. The CO_2 rate is then adjusted so that a full-scale deflection is obtained with standard sensitivity when the sample tube is connected to the gas box. This is checked between each reading taken with the probe. The proportion of full-scale deflection obtained is thus a direct measure of the proportion of air from the gas port contained in the sample taken by the probe.

By this means the exact sensitivity of the instrument does not require to be known, provided that the calibration response is linear. This is important as the sensitivity will vary if the concentration of CO_2 in the air supplied by the fan varies. Since the rate at which CO_2 is supplied by the cylinder is measured, the check on readings of samples from the gas box provides a check on the constancy of the sensitivity of the instrument, which can be re-adjusted by pre-set control if necessary.

An advantage of the instrument is its high sensitivity to a comparatively innocuous tracer. In this experiment the total volume of air used may be as high as 300 cu. ft./min., but by using an instrument capable of full-scale deflection for one part in 3000 the flow rate of CO_2 is reduced to less than $\frac{1}{10}$ cu. ft./min., at which rate a steady flow can easily be attained. Furthermore, since the concentration at which the gases leave the model is only 0·01%, no provision need be made for waste-gas extraction beyond a normal ventilating system.

The Model

In constructing the model, the following features were desired :

(1) Close geometrical similarity to the original, in the first part of the furnace and in the ports and uptakes.

(2) A flow roughly corresponding to that of the original, beyond this point.

(3) The easiest and quickest possible method of removing the furnace end for alterations.

(4) Freedom of movement for the probe.

The model consists essentially of a rectangular box made to the overall internal dimensions of an 80-ton furnace at $\frac{1}{12}$-scale. Glass panels are let into the sides, the top, and part of the bottom. In the bottom a rectangular hole is cut corresponding to the first 13 ft. of the furnace. Through this an accurate model of this part of the furnace can be inserted mounted on a base plate. The air uptakes which emerge from the lower side of this are contained in the large air box which is bolted beneath the box and which supports the model on its base plate. The glass panels of the top of the box are removable so that a further section of model can be added if required. There is a rectangular window in the end of the box so that when the model is in position a model gas port can be joined to it with bolts, locating the two accurately in position with regard to one another. The gas uptake is joined to a wooden gas box mounted on the framework which supports the whole apparatus.

The probe is a length of brass tube supported in a stand, consisting of a base plate $23\frac{1}{2} \times 4$ in., of $\frac{1}{4}$-in. steel, with an upright plate welded at each end. A series of holes is bored at $\frac{1}{2}$-in. intervals in each upright. The probe is run forward through the two holes at the height required until a projection on it comes up against the back upright. Marks are made on the floor of the box so that when the stand is placed on them the probe projects to known positions in the furnace end. Tests have shown that the distance of the end of the probe from the nearest part of the stand has no effect on the readings obtained.

Wood, plywood, perspex, and cardboard were tried

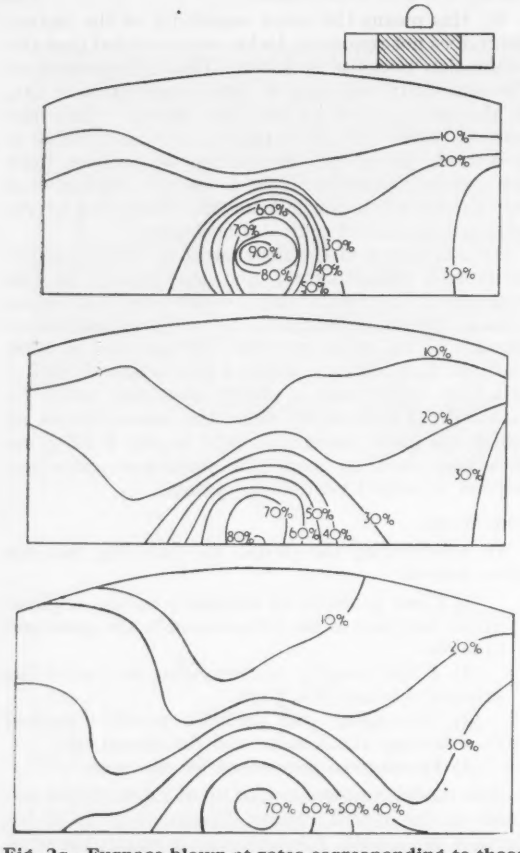

Fig. 2*a*—Furnace blown at rates corresponding to those used in practice; air/gas ratio 1·2:1

as the material for the construction of the models. The best results were obtained on a model incorporating all four. Stiff cardboard is particularly useful in making modifications to the size and shape of the ports and uptakes.

Air flows into the model from the ports and out from its open end into the main box. The main box is open at the far end as this does not affect the results but adds to the ease of manipulating the probe.

Concentrations are plotted in the form of contour maps. Three sections of the furnace are chosen arbitrarily at distances of 3 ft. 10 in., 6 ft. 5 in., and 9 ft. 2 in. from the end wall, the first being where the slope of the roof alters, the third just before the first charging door, and the second about half-way between them. At every foot across this section, from front to back wall, and from floor to roof, a sample is taken to determine what proportion of the gases passing the point has come from the gas port, and the result is expressed as a percentage.

A plan of the section is then made and the gas concentrations so determined are marked on it at points on the plan corresponding to the points in the section at which the measurements were made. Contour lines are drawn through points of equal concentration, with an interval of 10%. The figures are removed for the sake of clarity once the contours have been drawn.

Furnace Designs Tested

The results contained in this report are confined to furnaces* of the Maerz type, having a gas port

* Measurements are full scale, *i.e.*, 12 times measurements of the model.

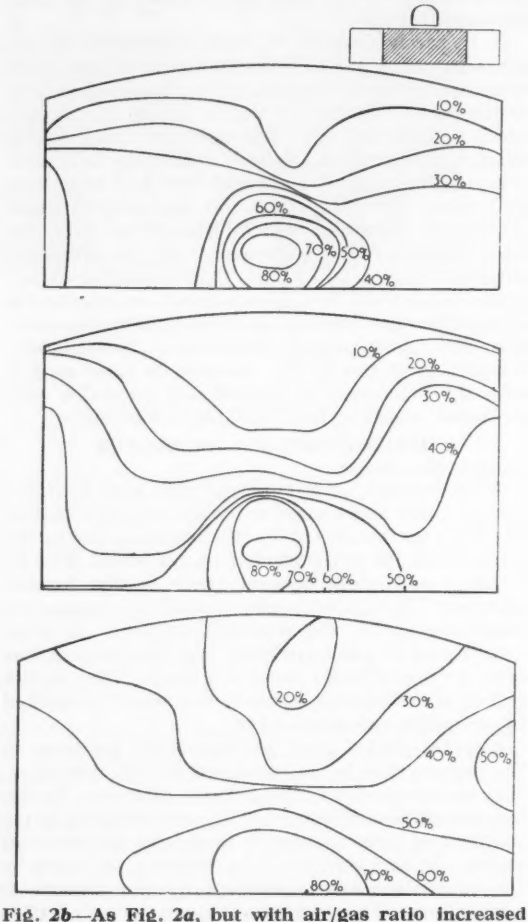

Fig. 2*b*—As Fig. 2*a*, but with air/gas ratio increased to 1·35:1

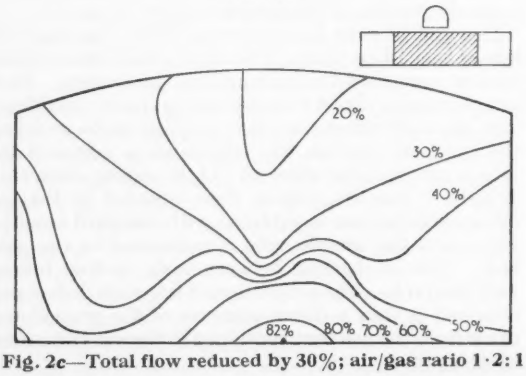

Fig. 2*c*—Total flow reduced by 30%; air/gas ratio 1·2:1

that does not project into the furnace, no knuckle in the roof, and an air port or ports in the floor of the furnace against the end wall. Later reports are intended to deal with Venturi and other designs. Types 2*a* and 2*d* (Figs. 2*a* and 2*d*) are based on the *K* furnace of Messrs. Steel Peech and Tozer's Templeborough Melting Shop, as it was at the time when the trials described in *Special Report No.* 37 were made. Figure 2*a* shows this furnace blown at rates corresponding to those used in practice, the air/gas ratio being 1·2 : 1. In Fig. 2*b* the ratio is increased to 1·35 : 1, and in Fig. 2*c* the total flow is reduced by 30%, the ratio being kept as in Fig. 2*a*. In this case a single section was considered sufficient, as even at the last section the differences were less than the probable experimental error. Figure 2*d* shows the effect of decreasing the gas-port area, while maintaining the standard rate of gas flow by increasing the pressure in the uptake by about 2½ times.

The designs of type 3 (Fig. 3) are similar to those of type 2 (Fig. 2), as regards the walls, floor, and roof, but the air ports are altered so as to be similar to those used by Leckie and others[3] (*see* Part III) in scale-model furnace trials. In Fig. 3*a* a single air port, 1 ft. 2 in. × 11 ft. 2 in., extends across the width of the furnace and has an area equal to that

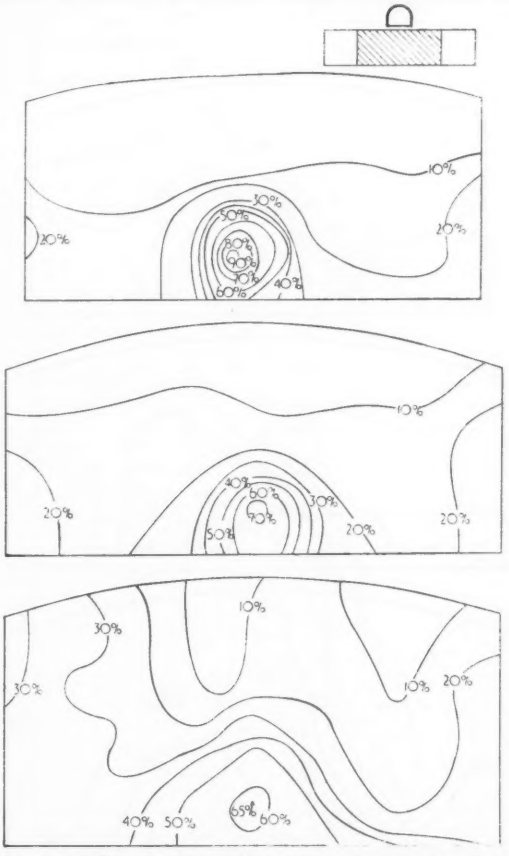

Fig. 2*d*—Effect of decreasing gas-port area; standard rate of gas flow maintained

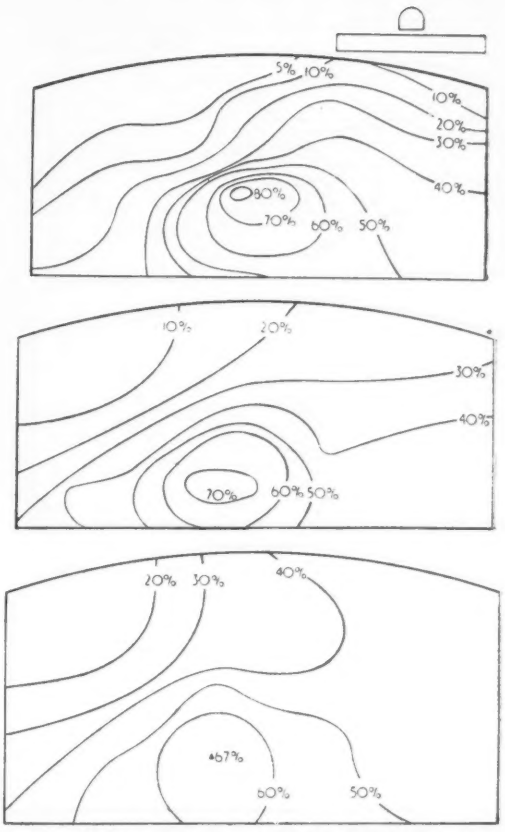

Fig. 3*a*—Single air port, 1 ft. 2 in. × 11 ft. 2 in., extending across width of furnace; area equal to combined area of the two ports of Fig. 2*a*

of the two ports of Fig. 2*a* combined. Figure 3*b* differs in reducing the dimensions of the single air port to 1 ft. 2 in. × 6 ft. 2 in. In order to reduce the air velocity while preserving the central air port, models 3*c* and 3*d* have air-port dimensions of 2 ft. 6 in. × 11 ft. 2 in., and 2 ft. 6 in. × 6 ft. 2 in., respectively. The performance of the latter port led to its adoption for tests with a gas port of different shape. A short, broad, arched port (Fig. 4*a*), of width 4 ft. 1 in. and maximum height 11 in., was tried, having a total area of 2·4 sq. ft.

To improve control of the flame position a portion of the sides of this gas port was blocked up, reducing its area to 2·08 sq. ft. and its breadth to 2 ft. 10 in. (Fig. 4*b*). Other methods of keeping the flame nearer the floor are to increase the slope of the gas port or the size of the air port, thus reducing the air velocity. Figure 4*c* is an arched port having a maximum height of 11·4 in. and sides of 5·4 in. The breadth is 3 ft. 7¾ in. and its area is 2·91 sq. ft. The slope is 1 in 4·7 instead of the 1 in 5·9 of all the other gas ports. Figure 4*d* shows this gas port used with another, larger, central air port 2 ft. 6 in. × 8 ft. 1 in. The same gas port is used in Fig. 4*e* with the original *K* furnace air ports. For comparison with these results a single model of a semi-Venturi furnace,

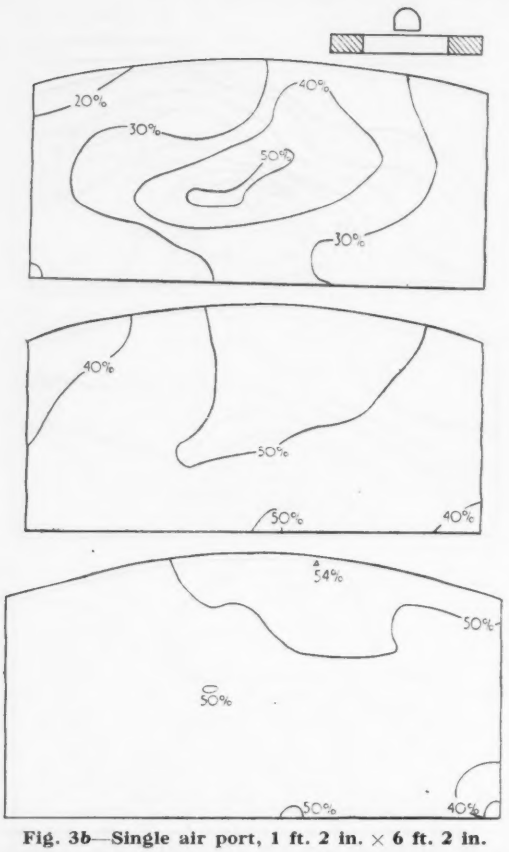

Fig. 3b—Single air port, 1 ft. 2 in. × 6 ft. 2 in.

based on *S* furnace, also at Templeborough, is included (Fig. 5).

RESULTS

Mixing Index

To enable a direct comparison of the mixing efficiency to be made, the proportion of unmixed gas which passes the third section (first charging door) has been calculated for some of these designs (Table I). Measurements of air velocity are made over the section in the same position as the concentrations. If the velocity at a point is multiplied first by the concentration of unmixed gas at the same point and then by the element of area of which it is representative, the product is the volume of unmixed gas flowing through the element in unit time. Summing over all the elements making up the cross-section gives the total rate of flow:

$$Q = \int cv\,dA$$

where c = concentration of unmixed gas
v = velocity crossing the section
dA = element of area
Q = flow of unmixed gas across the section.

The value of c, the concentration of unmixed gas, is calculated from the measured concentration of gas. At points near the outgoing end the mixing is complete and a concentration traverse shows a constant reading. This final mixture, say y% of gas and $100 - y$% of air, is regarded as containing no unmixed gas. If, at some point in the furnace, there is found to be a higher proportion, say x% of gas, it is considered as being made up of final mixture and excess gas. Since there is $100 - x$% of air present:

$$\frac{y}{100 - y}(100 - x)$$

of the gas must be allotted to it to make up a final mixture, leaving an excess as unmixed gas of:

$$x - \frac{y}{100 - y}(100 - x).$$

For perfect mixture $x = y$, and the index is zero.

There is a practical analogue to the mixing index, for if the air/gas ratio used corresponds to theoretical combustion it represents the proportion of the available chemical heat not yet liberated at this section, subject only to the approximations introduced into the experiment. But it is itself purely a measure of the mixing efficiency of the design under the given conditions and is not connected with the calorific value of a particular combustion gas.

Velocity was measured with a round-nosed N.P.L. type pitôt and static-head tube, pointing towards the incoming end, and the results were taken to indicate the component of velocity parallel to the length of the furnace. Owing to back flow, many of the readings were negative and were ignored, as these

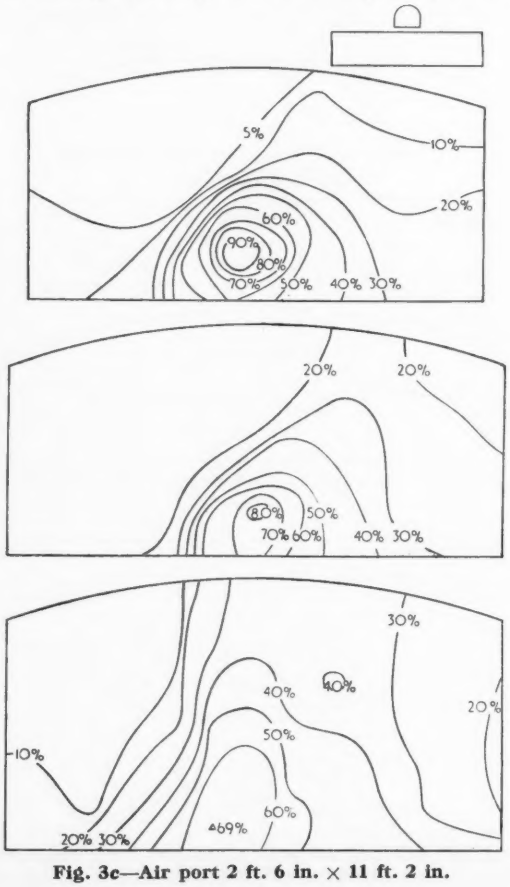

Fig. 3c—Air port 2 ft. 6 in. × 11 ft. 2 in.

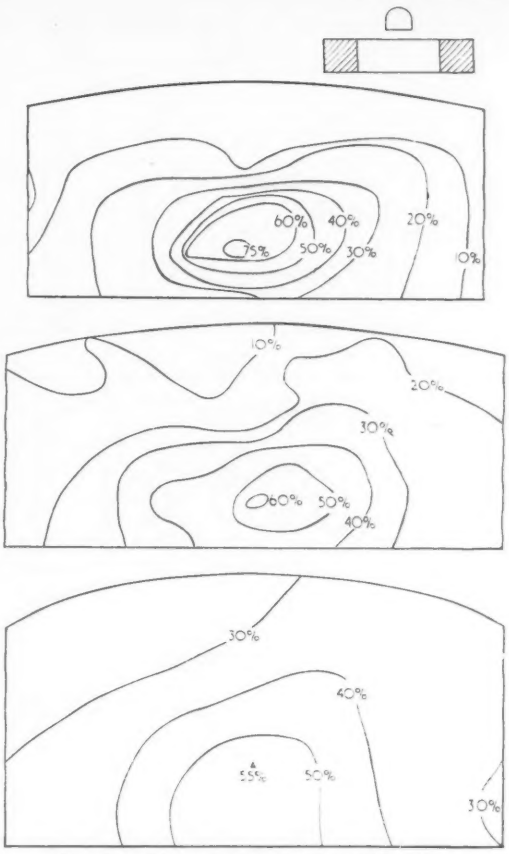

Fig. 3*d*—Air port 2 ft. 6 in. × 6 ft. 2 in.

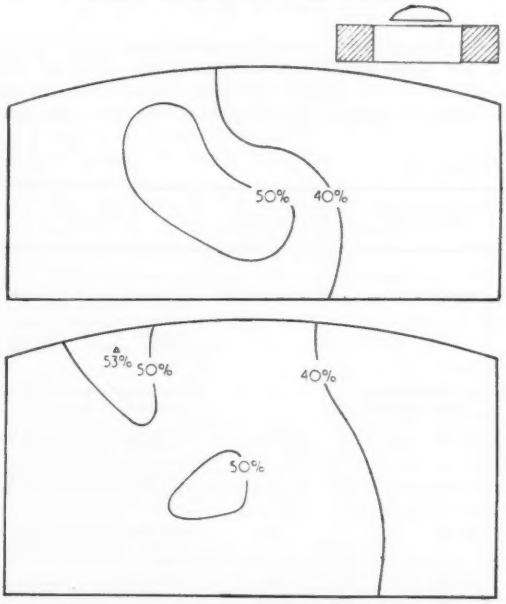

Fig. 4*a*—Air port as Fig. 3*d* ; short, broad, arched gas port, 4 ft. 1 in. wide, 11 in. max. height, total area 2·4 sq. ft.

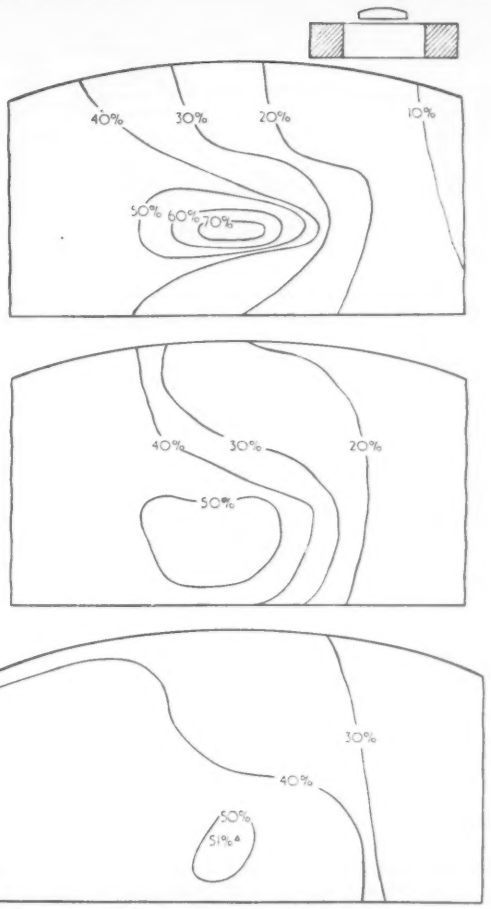

Fig. 4*b*—As Fig. 4*a*, but with area reduced to 2·08 sq. ft., and breadth reduced to 2 ft. 10 in.

parts do not contribute to the flow of unmixed gas in the direction considered. In most cases there was no unmixed gas concentration in these regions, and in no case was it large.

These figures should be regarded as approximations since, in the case of a well-mixed section, a small error in concentration or in experimental air/gas ratio produces a much larger error in the final figure.

Discussion of Results

The technique used has been developed during the course of these experiments. Consequently, in the earlier experiments especially, repetition of trials showed changes in detail. For this reason, comparatively large changes were made between trials to minimize the effect of random variations. In later work more detailed changes were attempted.

In Fig. 2*a* the main characteristics of a conventional Maerz design are clearly indicated. The flame is seen to follow the hearth closely, spreading sideways as it goes. The large area in the centre, to which very little air has penetrated, suggests the relatively slow-burning heart of the flame, while the small separation between the 40% (excess air) and 50% (excess gas) contours corresponds to an area of active burning.

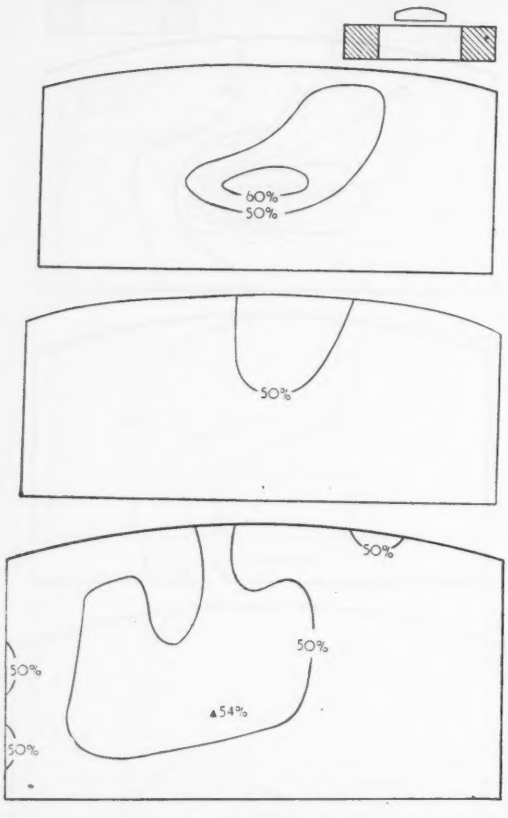

Fig. 4c—Gas-port slope and area increased (1 in 4·7 and 2·9 sq. ft.), otherwise as Fig. 4b

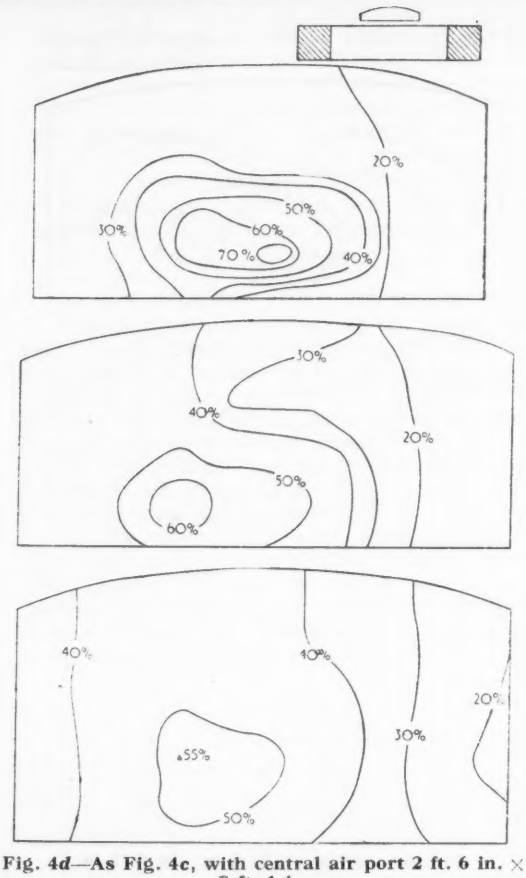

Fig. 4d—As Fig. 4c, with central air port 2 ft. 6 in. × 8 ft. 1 in.

The 10% gas lines indicate the path of the air flowing along the roof towards the centre-line caused by the upward-flowing air striking the curved roof.

Figures 2*b* and 2*c* show similar features, the changes due to the altered operating conditions being small and not significantly greater than the error of the experiments. In Fig. 2*d* an attempt has been made to improve mixing by increasing the gas velocity.

Table I
TABULATED SUMMARY

Figure	Design	Perimeter/Area Ratio	Turbulent Diffusion at Boundary	Exclusion of Back Flow	Mixing Index	Notes
2*a*	Original					
2*d*	Small gas port	25% increase	Unchanged or very slightly improved	Unchanged	Not measured	Impracticable design, would require 2½ times as much pressure in gas uptake as 2*a*. Mixing intermediate between 2*a* and 3*d*
3*d*	Central air port	Effective perimeter increased	Very high at lower surface	Excluded from lower surface	22	Best design tested with unchanged gas port
4*c*	Crescent gas port, central air port	Increased beyond 3*d*	As 3*d*	As 3*d*	19	Good mixing, but gas stream blown toward roof. Apart from roof damage, tends to screen upper surface of gas stream
4*d*	Crescent gas port, enlarged central air port	As 4*c*	As 4*c*	As 4*c*	16	Gas stream low in furnace. Very good mixing
4*e*	Crescent gas port, original air port	Small *effective* increase in perimeter compared with 2*a*	As 2*a*	As 2*a*	36	Steep slope of gas port produces high degree of stratification and mixing pattern similar to Venturi type

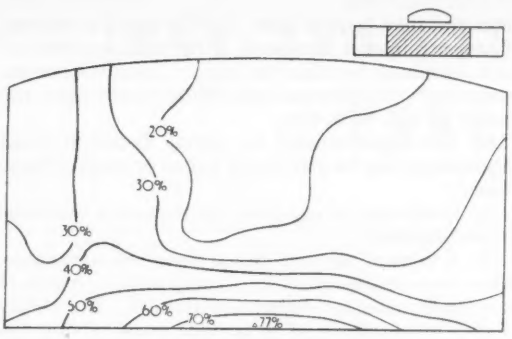

FIG4E

Fig. 4e—Gas port as Fig. 4c, air ports as Fig. 2a

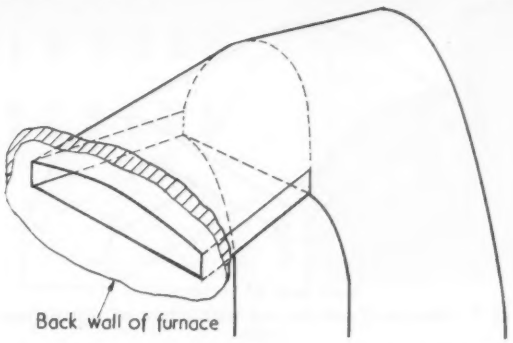

Fig. 6—Design of flat arched port for use with standard uptake and elbow

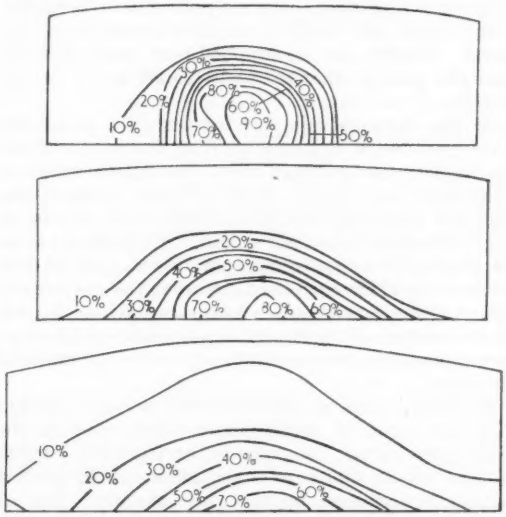

Fig. 5—Semi-Venturi type port; gas/air ratio 1:1·45

The improvement is marked, the highest reading in the third section having dropped from 70 to 65%, but it must be remembered that the gas-port area required needs 2½ times as much pressure behind it as that of Fig. 2*a*.

In Fig. 3*a* (single, long, narrow slit) a similar improvement is made without any change in gas or air velocities. In this design it is to be noted that the core of the flame is completely surrounded by lower concentrations of gas. The area between the 40 and 50% lines is larger, and a greater proportion of the section carries an appreciable quantity of gas.

Confining the air port to the centre of the furnace and increasing the air velocity provides very good mixing indeed, as shown in Fig. 3*b*. Unfortunately, the diagram of the third section, with high concentrations appearing only against the roof, shows that the flame has been blown upward. Comparison of the other sections shows that it hits the roof between sections one and two.

To keep the position of the flame down on the hearth, a wider air port is used in Figs. 3*c* and 3*d*. A comparison of mixing between types 3*c* and 3*a*, or 3*d* and 3*b*, shows the wider port to be at a disadvantage, but the flame is kept down on to the hearth and away from the walls. Figure 3*d* is a very good combination of flame shape with quick mixing. A further considerable improvement in mixing is effected (Fig. 4*a*) by altering the shape of the gas port so as to decrease its height. The flame shape, however, is now poor, since a tongue of flame appears to be licking the roof by the third section. The rest of the flame, however, is well down in the furnace. To increase flame control, the area of the gas port was reduced by blocking up the sides. This reduction in area would necessitate a 70% increase in gas pressure, as compared with Fig. 2*a*. The result shown in Fig. 4*b* is seen to be extremely good, rapid mixing being combined with a flame which holds together well. In this model the effect of back flow is seen particularly clearly. The main jet of gas travelling at high velocity is unaffected, and the higher concentrations are symmetrically placed, but where there is reverse flow along the back wall, concentrations similar to those at the outgoing end of the furnace occur. Where the back flow is less, direct flow from the air port produces low gas concentrations, so that outside the 50% line there is a large area greater than 40% bounded by a steady falling-off in concentration. When the gas-port area is increased again to 2·9 sq. ft., it is found that an increase in gas-port slope to 1 : 4·7 is not quite enough to hold the flame down (Fig. 4*c*). In Fig. 4*d* the size of the air port is increased to 8 ft. 1 in. × 2 ft. 6 in. to keep the flame down. Mixing is seen to be almost complete by the first door. Concentrations at the roof are everywhere as low as, or lower than, those immediately below. Along the hearth, except immediately under the flame, there is excess air. It has been suggested that furnaces with this latter characteristic shorten the refining times.

The satisfactorily low position of the flame in this design was clearly seen in the velocity measurements made to evaluate the mixing index. A considerable region of back flow was evident, but no measurements of reverse velocities were made. The flame is about 1 ft. closer to the back wall than to the front ; this is apparently due to the gas port being inclined in this direction. A few readings of velocity taken with the gas port moved through an angle of 5°, to bring the maximum velocity to the centre of the furnace, confirmed this.

To enable the flat arched port to be used with the

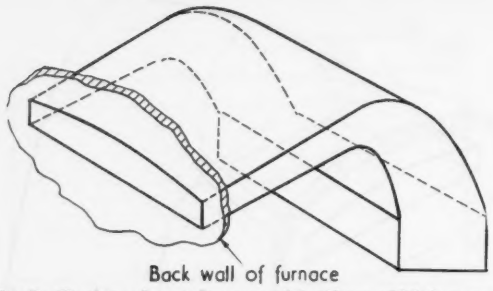

Fig. 7—Design of port for use with elbow of high aspect ratio

same uptake and elbow as the conventional port, the shape shown in Fig. 6 was adopted. A better design might be to use an elbow of high aspect ratio, for which a lower friction factor might be expected; the port would then be as in Fig. 7. Without the diverging sides lateral flame control might be better. A water model could easily verify this point.

Figure 4*e* is the third section of a furnace with the flat arched gas port and the original air ports. The gas has been spread over the hearth by the steep slope of the gas port. As no air can get into it from below, mixing is slow (*see* Table I) and stratification is very pronounced. The result is similar to that obtained with a semi-Venturi type, except for the increasing concentration of air at the centre of the roof, which is preserved from Figs. 2*a* and 2*e*.

Figure 5 (semi-Venturi) is characterized by the even stratification of gas and air from hearth to roof, and by slow mixing. The gas/air ratio is that used in practice on this furnace (1 : 1·45). Without this excess air the concentrations would be even higher.

A noticeable feature, particularly of the first two sections, is that outside the closely defined gas stream the gas concentration is very low; in fact, in the first section, the majority of readings were less than 8%. This clearly shows that there is no appreciable back flow of mixed gas into the region between the end wall and the throat of the furnace.

CONCLUSIONS

In Maerz-type furnaces there is no throat or knuckle. Improved mixing is obtained by the use of suitable air- and gas-port designs. Since the highest concentrations of unmixed gas occur in the middle of the gas stream, the problem is to enable air to diffuse more rapidly into this region from outside. This can be done in three ways*:

(1) The distance from edge to centre of the cross-section of the gas stream may be reduced so that diffusion has to take place over a shorter distance. This may be looked on as decreasing the ratio of the cross-sectional area to the perimeter.

(2) Turbulent diffusion may be increased in some part of the gas stream, so that more fluid is entrained into the stream.

(3) By excluding the back flow of recirculated waste gas from the region round the gas stream, the air entrained may be kept pure. In this way the amount of air entrained is increased, if the total quantity of fluid entrained remains the same. Visualization experiments[5, 6] by Chesters and Philip clearly show the extent of this back flow.

All the improvements in mixing found in these experiments can be attributed to one or more of these causes:

(1) Reduction of gas-port size decreases the area/perimeter ratio.

(2) A central air port has a threefold advantage. When two streams meet at a sharp angle a region of very high turbulent diffusion is formed. The ability of such an arrangement to provide quick mixing was one of the most important results obtained by Rummel.[4] In the second place, the effective perimeter of the jet is increased, since a supply of air is available to the lower side, which is usually screened by the hearth. Thirdly, the air supplied here comes directly from the port so that no recirculated gas is mixed with it.

(3) The flattened gas port increases the perimeter of the gas stream, as it emerges from the port, without altering its cross-sectional area. The improvement is maintained only for a short distance downstream since jets naturally tend to a circular cross-section at large distances from their origin. If advantage is to be taken of this type of gas port there must be free access of air to the increased surface of the gas stream. Thus the improvement is greatest when this is used with a central air port, and least when a high-slope port spreads the gas over the hearth with conventional air ports.

In Table I these results are briefly set out, together with the value of mixing index obtained with the main types tested. As explained on page 465, a figure of zero would represent a design in which perfect mixing is obtained by the time the first door is reached.

Acknowledgments

The authors wish to thank Mr. M. W. Thring and Mr. M. P. Newby, who originally planned this experiment, for their continual help and encouragement; Mr. S. E. McEwen for his assistance in the experimental work; and Dr. J. H. Chesters, Dr. A. H. Leckie, Mr. S. W. Pearson, and Dr. P. O. Rosin for their kindness in reading and commenting upon the paper.

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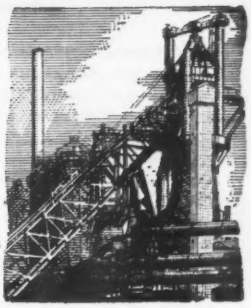
* It should be noted that a port tested in the form of a model by Allen, Cook, and Fenton satisfies all these conditions to a remarkable degree. The port is design No. 8 in their paper[3] (part III).

IRON AND STEELWORKS ENGINEERING

THE IRON AND STEEL ENGINEERS GROUP



THE IRON AND STEEL ENGINEERS GROUP

REPORT OF THE EIGHTH MEETING

The EIGHTH MEETING of the IRON AND STEEL ENGINEERS GROUP of The Iron and Steel Institute was held at 4 Grosvenor Gardens, London, S.W.1, on Wednesday, 24th November, 1948.

Mr. W. F. CARTWRIGHT (The Steel Company of Wales, Ltd., Port Talbot), Chairman of the Group, occupied the chair.

The MORNING SESSION was devoted to the presentation and discussion of a paper on "Specialized Rolling Stock for Iron and Steel Works," by T. H. STAYMAN and D. R. BROWN, and to the presentation of a paper entitled "Ore Discharging," by G. T. SHOOSMITH.

The AFTERNOON SESSION was occupied by the discussion of Mr. SHOOSMITH's paper which was published in the July, 1949, issue of the *Journal*, and by the presentation and discussion of a paper on "Belt Conveyors, Bunkers, and Chutes for Iron and Steel Works," by J. BRIMELOW, published in the April, 1949, issue of the *Journal*.

PROCEEDINGS OF THE MORNING SESSION: 10.30 A.M. to 1 P.M.

Discussion on—

SPECIALIZED ROLLING STOCK FOR IRON AND STEEL WORKS*

by T. H. Stayman and D. R. Brown

Mr. **T. H. Stayman** (Head, Wrightson and Co., Ltd.), who presented Parts I, IV, and V of the paper, said: The problems of material handling vary from plant to plant. Some of the factors influencing designs are: Type and nature of ores; number of furnaces; length of run; strength of supporting structures; number of types of ore. In laying out a new plant, most of these can be arranged to give the most efficient equipment, but if a car has to be designed to suit an existing plant the size may be determined by the load which can be carried by the bin structure, in which case the variables in design are filling and discharging time, and the speed of the car; but if the structure is to be designed to suit the car, a further variable, car size, has to be considered. The tare weight of a transfer can be taken as approximately 75% of the pay load, and figures for actual cars constructed show that a 50-ton car weighs 37 tons, and that a 100-ton car weighs 75 tons.

The cost of a car is increased very considerably when changing from a 4-wheel car to a bogie car, the additional price being in the cost of construction of the bogies; hence if the gross weight of a car exceeds about 70 tons, which is about the limit for 4-wheel cars, it would be advisable to go to 130 tons gross weight, which is the limit for 8-wheel cars.

The size and type of slag ladle are influenced by the amount of slag made, by the length of run to the tip, and also by the clearances around the furnace. The cost of each air- or steam-dumped car is high. The price of a 400-cu. ft. ladle and car is about four times that of a 10-ton chain-tipped ladle and car, but its capacity is approximately three times that of the 10-ton ladle. In addition, the length over buffers of the 400-cu. ft. car, which is shown in the paper as 24 ft. 2 in., is actually 24 ft. 6 in., while the length over buffers of three 10-ton cars is 45 ft.

Ingot bogies are influenced by the size, number, and weight of ingots, and also by the height of the casting crane. Bogies with welded-steel bodies are working satisfactorily, and so are bogies with cast-steel bodies: there is very little difference in price.

The acceleration demanded by users varies considerably, and although in the paper I have given a figure of 1·5 ft./sec./sec., to suit a special case, I know that electrical manufacturers would prefer 1·2 ft./sec./sec., or even less. One electrical manufacturer had asked for the figure to be kept to 0·8 ft./sec./sec.

* *Journal of The Iron and Steel Institute*, 1948, vol. 160, Oct., pp. 197–212.

In most cases the electrical equipment must be designed to suit the job, but certain conditions, such as speed of car, and rate of acceleration, could be agreed for cars of various sizes, with consequent saving in development time.

Opinions differ widely as to the tractive effort necessary to start rolling stock, and to keep it moving. Several tests have been made and a wide range of values produced. The figures given in the paper are those that have been used in our design department for several years, and I should hesitate to use anything lower.

On page 197 I say, " Cars with a capacity appreciably in excess of 60 tons should be carried on six-wheel bogies." That figure of 60 tons should, in fact, be more like 80 tons. On page 198 I say, " The impact of the wheel against rail heads dissipates energy in heat into the wheel." That is true to some extent, and some energy is dissipated in this way, but it is not much.

On page 211, in the caption to Fig. 12, the reference to throwers fitted to both sides of the box should be deleted.

Mr. **D. R. Brown** (Ashmore, Benson, Pease and Co., Ltd.), who presented Parts II and III of the paper, said : We are today considering the methods used for handling the vast quantities of materials which must be continuously moved in a modern iron and steel works. In this connection, scale cars and hot-metal ladles play an important part.

The term " specialized rolling stock " is used to denote cars and ladles which have a special duty to perform, not found outside the iron and steel industry, and it does not imply that each works should use its own special equipment and have its own individual specifications. With the collaboration of operating personnel, a considerable degree of standardization can be achieved.

On page 200, under the heading " Function of the Scale Car," I refer to the weight of materials to be handled for three typical furnace outputs, and I give three illustrations of scale cars and suggest that each car may well fit each set of circumstances. This is intended to form a basis for discussion on the sizes of car best suited for standardization.

You may feel that the scale-car performance tables are hardly consistent with the requirements ; the single-hopper type *A* car is shown to be standing for about half of its time, and the double-hopper type *B* for two-thirds of its time, when filling a furnace making 650 tons a day. The object of putting the figures before you is that we may hear views on how hard a car should be worked. The figures are illustrative of what cars are actually doing in two large plants today : they are not maximum figures, nor are the data necessarily applicable everywhere. Those with home ores may have to allow longer times for the scale car operator to get material out of the bins. All tests were carried out in the course of the normal day's work. No one in this country has yet required the large 8-wheel type *C* car. Ultimately, we may have to use these very large cars and if so, the designs are available, and cars of this kind are in service in America.

The tractive effort figures for hot-metal ladles may appear to be high, but they are not the result of specially prepared tests. A crude dynamometer was inserted between the locomotive and the various carriages, and each complete ladle and carriage was pulled round the works. This means that the tractive effort quoted as required to move ladles, is measured on a track which the steelworks operator would consider reasonably level. The ladles had not been specially greased for the tests, but were taken at random from ladles found working round the furnaces at the time.

Mr. **E. R. S. Watkin** (Appleby-Frodingham Steel Co.) : We should not write off the chain or rope-tipped ladle as something of which no more is to be heard. We have used the 330-cu. ft., steam-tipped ladle since 1939, and have also reintroduced the 250-cu. ft. rope-tipped type. It is easy to get fluid slag out of either, by pouring, or through a tap-hole, but with our slag the bottom part of the skull is very difficult to dislodge. The ladles are lime washed, but we should be glad to hear of any more effective treatment. With steam tipping, the ladle bumps too lightly against the frame, and up to fifty attempts may fail to shift the skull. The piping suffers during these attempts, and effective pressure is then confined to ladles near the locomotive. With rope tipping, more violence can be used, and the skull can be removed more surely, even if broken ropes and dented tracks are left beyind. We hope to regain the 330-cu. ft. capacity by fitting this size of ladle into our rope-tipping carriages.

Experimentally, after failing to dislodge skulls hot or cold at the bank, we have taken the ladles to an overhead crane and inverted them. In every case the skull has dropped out as soon as the ladle is upside down. This suggests that there may be a future for an entirely new type of ladle, with 30 tons, or even 60 tons capacity in a bath-tub shape, not designed for tilting. Fluid slag would be removed through tap-holes and the ladles would then be inverted by a crane over a pit. The skullings would have to be excavated, but they would form a small part of the slag from ladles of such size.

Returning to the traditional tilting ladle, I doubt if a tapered shape is the best for removing a skull by rotary shock. Would a hemisphere be better geometrically and also thermally, by reducing skull formation in the bottom ? A 10-ft. dia. would give 250 cu. ft., and an 11-ft. dia. would give 330 cu. ft. Loading gauge would not permit a supporting ring near the top of such a ladle, but it might be possible to attach steam-tilting gear to the ladle itself, or to apply a pulley block at a lower level.

Roller bearings are so successful that carriages so fitted will not stand still on the slightest incline. Some braking effect is desirable when shunting or setting ladles, and there is probably a case for applying roller bearings to half the axles.

Mr. **T. H. Stayman** : With larger furnaces and more slag, either a succession of small ladles or bigger ladles must be used. In reducing the extra time in tipping and the requirements of space round the furnace for standing ladles, the bigger ladles have an advantage. Some time ago my firm made a ladle which we called a ' 20-tonner,' with a capacity of approximately 330 cu. ft., tipped by chain, and we had a great deal of trouble with it. It is still in use, but the experience has never been repeated. With a very large ladle, to maintain the right proportions, the height must be increased and the diameter increased, but it is doubtful whether such a ladle would fit under the slag runners of any existing furnace, and it would certainly be necessary to widen out the tracks. The ladle with a small bottom has grown up from the fact that a certain incline is necessary when the ladle tips over, and to get that incline a small bottom is used.

I would not like to see one roller bearing and one plain bearing on the same vehicle. A hand-brake is preferable to mixing the two types of bearing.

The **Chairman** : Is there any logic in the proportion of the hoppers in the scale cars to the size of the skips ? Where did you get the idea that you would need a double-bogie car of the 33-ton type for a furnace making 1200 tons a day ? Surely it should be 2000 tons a day, or at any rate a very much bigger figure than 1200 tons, because the hopper for a furnace making 1200 tons a day is not as big as 275 cu. ft. ?

Mr. **D. R. Brown** : The scale-car hopper size equals that of the skip-tub so that, in an emergency, coke may be

charged by the car. I describe the 33-ton car as being suitable for furnaces making from 1200 tons per day up to the maximum now foreseen.

We have recently had enquiries for double-hopper, 250-cu. ft. cars, to suit 250-cu. ft. skip-tubs, for a projected furnace of 1200 tons per day ; so I envisage a standard car that could be fitted with hoppers from say, 225 cu. ft. to 275 cu. ft.

Mr. **C. S. Clarke** (Skefko Ball Bearing Co., Ltd.): Mr. Stayman has given us some very interesting information with regard to bearings for ingot bogies and slag ladles, but in Fig. 13, page 212, he shows a roller bearing arrangement which is not, I think, in accordance with standard practice. Reference should be made to Fig. 3 of the report on locomotives for iron and steel works published by B.I.S.R.A.,* which illustrates a wheel-mounting for a slag ladle or ingot car, and makes use of self-aligning roller bearings. This arrangement was used for a number of years before the war, but, unfortunately, during the war, self-aligning roller bearings were not produced or were not available in sufficient quantity to meet all requirements, and the case of the ingot-car wheel was put up to the Bearings Technical Advisory Committee of the Ministry of Supply, with the result that the design shown by Mr. Stayman was, I think I might say, forced upon the trade. This mounting has the distinct disadvantage that it has only about half the capacity of the self-aligning roller-bearing scheme, and when we bear in mind the abuse which can, and does, occur with equipment of this type I think it will be agreed that the margin is extremely dangerous.

The cylindrical roller-bearing scheme also has the disadvantage that no ball- or roller-bearing location is provided, and recourse has to be made to plain collars. Under the temperature conditions which prevail, the coefficient of friction must be extremely high, particularly at starting. It is interesting to note that the user of the improvised cylindrical roller-bearing scheme has since reverted to the self-aligning roller bearings.

Mr. **F. C. Doherty** (Stewarts and Lloyds, Ltd.): I note with interest Mr. Stayman's remarks on the possibilities of being able to couple and uncouple ingot bogies, without having to stand between them. In these days of an increasing regard for safety, this is a matter of some importance. It would seem, however, that most schemes directed to this object are defective, inasmuch as they either make the bogies permanently 'handed,' with male and female connections, so that special care has to be exercised when marshalling, or else they still necessitate intervention of a person between adjacent bogies, in order to place or remove a link, should bogies with the same end connections come together. In particular, the connection between locomotive and bogie, whilst being the most necessary to make indirectly, is also the most difficult, on account of the locomotive buffers.

At Corby, we have considered equipping bogies and locomotives with automatic couplings, I should be interested to learn whether these couplings have previously been used for this extremely severe duty.

Mr. **J. H. Pearce** (English Steel Corporation, Ltd.): When slag ladles and ingot cars are moved about, it is much safer if the operator does not have to go between the cars for coupling purposes. The following illustrations show some types of couplings capable of being unlocked from the sides of the cars.

Fig. A shows the Alliance type of automatic coupler in common use in the U.S.A. It is a simple form of top-operated coupler. It will be seen from the rigidity of the coupling that this helps to keep the cars together on the rails.

Fig. B is a simple type of drawgear and coupler, showing a simple knuckle-type coupler with a spring type of drawgear.

Fig. C shows a heavier coupler capable of taking drawbar pulls of 20 tons. This one is a bottom-operated type, with the operating gear well protected from damage by falling slag or other material. A shelf can be fitted above the coupler body to achieve a similar purpose.

Fig. D shows a transitional type of coupler, capable of swivelling about a back pin, and of being thus dropped out of the way, if the stock has at any time to be coupled up to normal rolling stock fitted with hook and link couplings.

Fig. E shows the 'Willison' type of coupler, to be used at one of the newer steelworks. It has an excellent buffing area, and incorporates the advantages of central buffing. It has a further advantage in that it is always ready to receive its mating coupler, and the ingot bogies, slag ladles, or special rolling stock to which this coupler is fitted, become coupled by the simple action of buffing together.

Mr. **C. Challoner** (Dorman, Long and Co., Ltd.): Mr. Stayman, in the second paragraph, Part I of his paper says, "The material can be grabbed from the stockyard by an ore bridge and placed in an elevated hopper on the furnace high-line." I understand that where an ore bridge is used for loading furnace bins, the grab discharges direct into a transfer car, thus the elevation of the car determines the maximum height of bridge hoisting. If an elevated hopper is used for loading the transfer car, then

* E. L. Diamond : *Journal of the Iron and Steel Institute*, 1948, vol. 159, p. 48.

Fig. A

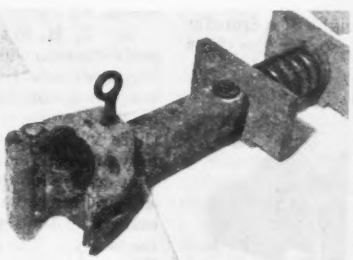


Fig. B

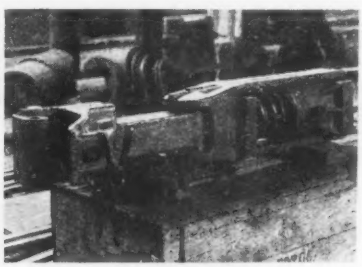


Fig. C

Fig. A—Alliance type of automatic coupler in use in the U.S.A. ; Fig. B—Simple type of drawgear and coupler with knuckle-type coupler and spring-type drawgear ; Fig. C—Heavy coupler capable of taking drawbar pulls of 20 tons

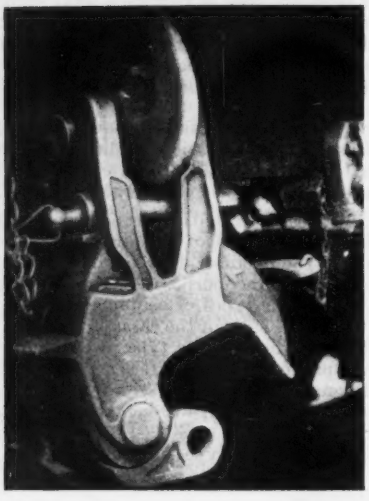


Fig. D—Transitional type of coupler

the height of the ore bridge must be increased accordingly, thereby adding to the cost of the equipment. At the same time the hoisting cycle is slowed down due to the extra height required for the elevated bin. There may be some special reason for this method of loading transfer cars, and I would like a little further information on this.

I cannot agree with Mr. Stayman, when he states (para. 3), that, " for more than two furnaces, the conveyor belt system becomes very complicated and a transfer car should be used." I would like to assure Mr. Stayman that it is possible to serve three furnaces with conveyor belts without complications.

If the ore yard and ore bridge are adjacent to the furnace bins, then I agree that the transfer-car method of operation should be used, but at plants where the ore yard is some distance away, prepared materials, ore, and sinter are invariably conveyed to the bins by belts. With this system, the materials should then be loaded into the bins by belt conveyors and not by transfer cars operating in conjunction with super-elevated bunkers. If conveyors are used throughout, then super-elevated bunkers are not necessary, so there is saving in power consumption and less wear and tear on equipment handling considerable tonnages. For serving two or three large furnaces of 1000 tons per day, a conveyor with two or three trippers would deal with all the materials that the transfer car handles, and again there would be a saving in power consumption.

Mr. Stayman mentioned that the weight of a transfer car is about 75% of the load carried, so, for the three 1000-ton furnaces referred to, we might assume that the loaded transfer car is 175 tons. This is a considerable load to be allowed for when designing the bin structure, and in addition the end structure must be designed to provide for impact of the transfer car in the event of brake failure or skidding of the wheels. With conveyors, the loading is almost negligible in comparison with the loads mentioned, hence the furnace bins, foundations, and structures are much cheaper. Incidentally, at the Fairfield plant, Tennessee, the furnace bins are served by belt conveyors. There are three furnaces, Nos. 5, 6, and 7, the latter furnace being built in 1941, so that much experience has been gained, and I believe there have been no stoppages on the furnaces due to high-line failure. These furnaces make 2500 gross tons per day with about 6000 tons of low-grade ore. It should be mentioned that there are no rail tracks over the bins, so that they are entirely dependent upon the conveyor system for three large furnaces.

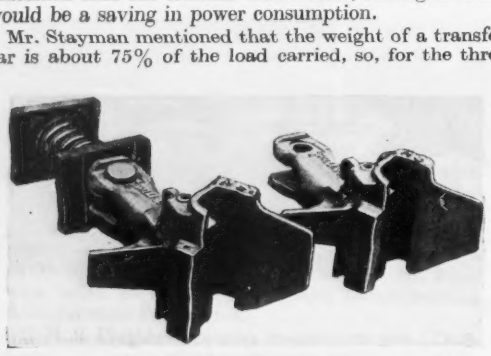


Fig. E—Willison type of coupler

With the conveyor system, the width or distance between the vertical bin sides can be much less than that required for transfer cars, as the long discharge gates, plus the extra length required for car-spotting, may require a bin width of, say, 15 to 16 feet. The possibility of having bins of less width enables a larger number of bins to be installed between furnace centres when more than two furnaces are in a continuous straight line. More bins allow the operators to take advantage of having various size materials of various ores, separated, so that layer charging can be used, and at the same time the run of the scale car is not increased. This advantage of more bins in the same space is most useful when five or more different ores are being used, which often occurs at plants in this country.

Apart from belt conveyors, both the straight Diesel and Diesel-electric locomotive with trailer car or cars must now be considered for doing the work previously done by the transfer car. The trailer car is a reasonably cheap piece of equipment and, when damaged by loading from the ore bridge grab, this car can be taken out of commission and easily replaced, while, on the other hand, if the transfer car is damaged then all the motive power is laid idle, thus adding considerably to the operating cost. Both types of Diesel eliminate the troublesome hot rails on the tops of bins, hence it is possible to have cross-over tracks over the bins instead of having to extend the high-line approach to provide for the cross-over. This reduces the costs of the high-line structure and of maintenance on the high line.

In regard to the double-hopper scale car referred to by Mr. Brown, type *B*, this requires only 52 h.p. to obtain acceleration. The car is fitted with two 45-h.p. motors, and it appears that two 25- or two 30-h.p. motors would be ample for the work. Is there any particular reason for fitting these larger motors ?

Mr. **T. H. Stayman** : In regard to the intention of grabbing into the hopper ; a fairly small car, and a fairly big grab which can fill it with one grab, is all right, but when working against time the transfer car must be brought along to the ore bridge, and allowed to stand there while three or four grabs are put into it, which may affect the running time and the amount of material that can be handled. In that case it is worth while considering an elevated hopper. On the other hand, if the car can be filled quickly by the ore bridge, a hopper is not necessary. The 75% extra weight on the bins is something which has to be faced. The transfer car will put a bigger load on the bins than will the conveyors. However, with three furnaces and four or five different types of ore going into each furnace, trippers must be placed first at one end and then at the other. If the furnace is being charged at the far end, the materials

must be passed right through, and at least two trippers are necessary : if the second furnace is working, all the material has to go over the first, and there will be trouble.

I had hoped to see the scheme at Fairfield, Tennessee, but unfortunately I did not have the opportunity. Several people said that it worked satisfactorily, but that they were not going to copy it, and nobody has copied it, as far as I know.

Compromise is necessary on the size of the gate ; it should be as wide as possible, within the limitations of the bin width.

On the question of the use of Diesel or Diesel-electric engines, I am in entire sympathy with Mr. Challoner. Hot rails are a nuisance. Some time ago we discussed the question of the use of Diesel and Diesel-electric engines with one of the Diesel manufacturers. We found that he could not mount a Diesel engine on an articulated car, and so we tried a trailer car with the Diesel motor, but we lost so much space at the end of the bins that the firm for whom we were working were not prepared to put on a sufficient gap at the end to take it. But I believe that there is a very definite future for the use of Diesels and Diesel-electric engines on this type of car.

Mr. **D. R. Brown** : The question, raised by Mr. Challoner, of motor size used on the type *B* scale car is justified, and I hope some of the figures now published will discourage users from demanding acceleration figures higher than are really necessary. In the case described, smaller motors would amply fulfil the task, and straight-series control used instead of series-parallel would simplify the control equipment.

Mr. **R. L. Willott** (John Summers and Sons, Ltd.) : In regard to slag ladles, my experience is confined to slag from open-hearth furnaces at Shotton, where we found that by splitting our ladle horizontally and having a detachable bottom, the top outlived the bottom by not less than twice, and frequently by four to five times. It might appear that the joint would give rise to some of the difficulties which Mr. Watkins has raised, but we have had no trouble due to this joint. I have no experience of large ladles handling big volumes of slag.

Mr. **T. H. Stayman** : I have had no experience of slag ladles with a detachable bottom. I can visualize that they might be worth while adopting, as a number of the ladles have failed at the bottom, and I shall inquire about this at the works.

Mr. **E. T. Judge** (Dorman, Long and Co., Ltd.) : I will not elaborate on the question, raised by Mr. Challoner, of the use of belt conveyors on the top of furnace bunkers, but I would point out that the Fairfield furnaces also have no scale car at the bottom. I do not advocate the abandonment of the scale car or of transfer cars, but I would point out that, although the development of existing types of equipment is extraordinarily good and very necessary, I think that we should not lose sight altogether of possible radical changes.

In regard to the question of the transfer car *versus* the locomotive, whether Diesel, Diesel-electric, or straight electric, with the coupled car with air-operated gates, the only disadvantage of the separate car is that on all transfer cars we put two cabs, one at each end. The driver is supposed to go from one end to the other so that he is always in front of his car, whichever way he is travelling. This is done for safety, and it cannot be done when working with a locomotive and a trailer. I wonder whether, in point of fact, when operating a transfer car with two cabs, the man does go from one cab to the other as he drives up and down the track. I think perhaps that it is an exaggerated safety precaution, which may not be followed on the job.

The question of twin- and single-hopper scale cars is very interesting and important. There is no doubt that many of our furnaces, and probably many American furnaces as well, are over-equipped with scale-car capacity, not in the individual size of the scale-car hoppers, but in regard to the rate at which the scale cars can put material into the skips. I wonder whether the twin-hopper car results from many American furnace bins not being equipped with mechanically operated gates. Many gates are hand operated. Possibly with the mechanically operated gate, which is more normal in this country, car filling can be done more quickly and, where we have installed twin-hopper cars, inherited from the American hand-operated gate system, we have provided more capacity than is necessary. It will be a brave engineer, however, who reduces the size of his scale cars below what is provided on American furnaces of similar size.

I do not see why Mr. Brown should not have wholehearted support for some degree of standardization of hot-metal ladles. But I suggest that, in considering standards, we should bear in mind that most of the present hot-metal ladles of modern design used in this country have come from American designs, with a greater allowance for clearances, height, and width than is usually available on British track layout. If we standardize for this country, the hot-metal cars should, if possible without compromising the design too much, be better able to travel round our existing works, and be closer to the normal British size limits for rolling stock.

Mr. Brown refers to the type of plant best served by hot-metal mixer cars, and implies that a large integrated works, with blast-furnace plant and two or more steel plants, is probably the type in which the hot-metal mixer car is most suitable. I wonder whether that is correct. At our plant we have that particular circumstance, and I doubt whether, even under these conditions, there is a case for the large, mixer-type 125-ton to 150-ton car—which means double handling of all metal going to the open-hearth plant. I think that the advantage in heat conservation of the mixer car over the Kling type is so small that it is hardly worth while going to the trouble of double handling. Has Mr. Brown any idea of how the capital cost factor applies ? Because there may be something in the mixer car from that point of view. He points out that on a 250-ton cast he can use four 75-ton Klings, or two 125-ton mixer cars. Is there a great deal in the comparative cost of those two equipments ?

Mr. Watkin has suggested that we might be thinking of something entirely different in slag ladles from those in use at the present time. We found, many years ago, that a round ladle with an almost hemispherical bottom, tipped by a crane, was very much better for clearing the skull than a Dewhurst type of similar size, and also that the maintenance charge was very much less.

Mr. Stayman mentions the possibility of installing compressors, specially at the tipping face, to provide the air for tipping the normal cylinder-tipped ladle. In certain circumstances there may be a case for providing for the crane-tipping of large ladles. It is difficult to say how our experience with small, round pots would compare with the larger sizes but where the tipping disposal point is a long way from the furnace, requiring a large number of ladles to be in service, there may be a case for providing crane or similar tipping arrangements at the face, and thus avoiding the mechanical gear on the numerous ladles which have to be provided. Once there is a design which allows the skull to come out fairly easily, a point of the greatest importance is that the ladle should throw the slag as far forward from the track as possible. One of the highest costs in slag

disposal arises from slewing the track. If it were possible to devise a slag ladle which would throw the slag forward, say, double the distance that the present equipment does, it would about halve the slewing cost. That is a problem which designers of slag-ladle equipment might well look into.

Mr. **D. R. Brown** : I agree with Mr. Judge that the speed of filling provided by a double-compartment car is difficult to justify but, as distinct from seeking for speed, there is the fact that the equipment need cover less distance to achieve its object, hence less wear and tear should ensue. Mr. Judge advocates that standard equipment might conform with clearances in our existing works. Within limits this is desirable, but most reconstruction schemes will surely provide for the use of equipment involving no abnormality of design, where this could be avoided by improving clearances or by the use of smaller equipment.

I can give no information in regard to the comparative costs of the mixer ladle and the Kling or barrel type. When spare ladles are taken into account, I think the cost comparison will certainly be in favour of the latter, for, in the instance Mr. Judge mentions, four Kling ladles and one spare pot would give continuous service, whereas three complete mixer ladles would be required. I do not intend necessarily to recommend the mixer ladle as particularly suited to works with two melting shops and perhaps two furnace plants, separated by a long distance ; I only point out that, if anywhere, this type of works would be the place for a mixer ladle, and my paper might be considered incomplete without mention of these large ladles.

Mr. **L. Newman** (Steel Company of Wales, Ltd.) : We are adopting at Margam a conveyor and a reversible-shuttle belt for serving coke to three bunkers at 155-ft. centres, and I cannot see why this system should not serve for ore as well.

Mr. Stayman gives the time-cycle for a 50-ton car, which appears to be the net travelling time, plus loading and dumping. We carried out a series of tests at Margam on a 4-wheel, 12-ton car and discovered that the theoretical time was very much exceeded, and that the actual working cycle came to some 50% more than the theoretical cycle. This was accounted for partly, we think, by unsynchronized car and transporter-crane working, and the human element. Possibly, in actual practice, Mr. Stayman's figure of six minutes would work out at about ten.

Mr. Stayman advocates the use of oil for pivot lubrication on the transfer cars. Bearing in mind the character of the atmosphere surrounding the car, I feel that pressure-grease lubrication would be a great improvement, and, in fact, we have adopted this form of lubrication on the bogies of the ladles at Margam and, as in automobile practice, dirt and dust are efficiently kept out.

Mr. Stayman quotes a figure of 80–85% block pressure of the transfer-car brakes, while Mr. Brown, for similar duties on a scale car, quotes 70%. Why is there this difference, and which is correct ? On the question of brakes on the transfer car, we are informed that in order to release the brake shoes it is necessary first to remove two pins, situated well up inside the plate frames of the bogie, which allows the shoe beams to be lowered clear of the plate frame. I submit that this is an unnecessarily complicated job, which can only be carried out over an inspection pit in the repair depot. In regard to the latter, no mention is made of a power plug on the car, which seems necessary in order to get the car into the repair depot, where there would be no live rails.

Lastly, whilst I realize that Mr. Stayman's specification is a condensed version, I submit that such vague terms as *high* factors of safety, *ample* proportions, *low* stress and deflection, etc., could well be replaced by specific values.

Mr. **T. H. Stayman** : Mr. Newman refers to the handling of only one material and to dealing with only three bunkers. My previous answer dealt with several different types of material transferred to several different bunkers at several different points. I think that the cases are not quite parallel.

In regard to the time-cycle, these are design figures, and if they do not work out like that I should like to hear from Mr. Newman.

On the question of oil lubrication *versus* pressure grease lubrication, there is a definite case for the latter where there is dust and dirt.

Mr. Newman refers to a different figure given by me from that given by Mr. Brown for the block pressure of the brakes. The figure which I gave was obtained as a percentage of the tare weight and takes account of the speed of the car. It is unlikely that the speed of the scale car will ever reach that of the transfer car, and therefore such a high block pressure is not necessary.

Our designers have been looking into the question of brake changing, and have produced a design which permits easier changing. On the question of live rails going to the repair pit, we have never had any call for a plug in, and we have always assumed that users would put the live rails there.

Specifications are a sore point in designing any equipment. It is usual to design to such of the British Standard Specifications as apply, with additions in the case of transfer cars so that special parts are in accordance with R.C.H. requirements. I think that this cannot be improved upon.

Very often we state the stresses to which we work, but in other cases they are stated very clearly in British Standard Specifications, and there is no need to repeat them. I would add that, in the estimating stage, while the sections are being designed, it is often found as the details proceed that a better section can be employed, so that it is unwise to have the design tied down too closely.

Mr. **A. E. Stock** (Steel Company of Wales, Ltd.) : For the past two years, we have had in operation at Margam works a 20-ton scale car of a similar type to that described by Mr. Brown. Having had some experience in the maintenance of this car, I should like to make the following remarks.

The loading of 25 tons per axle corresponds to normal main-line practice, and has proved satisfactory.

We have had the usual trouble with specifications of the main frame : definite *factor of safety* figures are never submitted with the specifications. It would be a help to everybody concerned if these figures were supplied.

We have experienced considerable trouble with the spring stops on the discharge gates. The U-bolts holding the springs continually break, and on occasions the springs and chain links have also had to be renewed. The speed of the gate opening has been reduced by means of the throttle valve, but this has not eliminated the trouble. We suggest that this gear should be of a more robust design.

The method of securing the pistons on the air cylinders is very poor indeed. The end of the piston rod is supposed to be riveted over to prevent the nut working loose, but on the Margam scale car these nuts have worked loose, and we have had considerable trouble with damaged U-leathers. We have drilled a hole through the rod and nut, and inserted a split pin, which has eliminated this trouble. We had similar trouble on the bin gate-operating cylinders, but in this case we had a little more difficulty because these are fitted with pistons rings, and the broken rings caused bad scoring of the cylinders.

There have been occasions when one of the control levers operating the discharge gates has been inadvertently moved when the car was away from the skip pit : the solenoid interlocking valve has failed to operate, and the load has been deposited on the car track. I should imagine that a more reliable type of interlocking valve could be fitted to the car to obviate this trouble.

We have experienced trouble with the drawhooks on the Kling ladles breaking on the 2-in. dia. portion, which is screwed to take the fixing nut, and we suggest that these hooks should be of a more robust design. To prevent a runaway through a coupling or drawhook breaking, safety chains have been fitted but, for various reasons, they have not proved satisfactory. We should like to know the authors' experience in regard to the fitting of safety chains or similar safety devices.

Mr. Brown quotes some useful figures in connection with the tractive effort required to keep a 70-ton fully loaded ladle travelling at a uniform velocity, but what is of more concern is the difficulty of bringing a train of three ladles to a standstill in a reasonable distance. Assuming that the three ladles are being hauled by a steam locomotive of the 0–4–0 saddle-tank type, weighing 53 tons and travelling at 12 m.p.h. on a level track, and taking the adhesion ratio at 4·5 : 1, and the locomotive rolling resistance at 14 lb./ton, and the rolling resistance for the ladle at 12 lb./ton (which works out at about Mr. Brown's figures), the distance required to stop would be 160 ft., and under similar conditions from 20 m.p.h. the distance would be 440 ft., which is the speed we expect to reach between the Margam and Abbey Works. This is alarming enough, but in greasy and in icy conditions those figures become 238 and 660 ft., respectively, and greasy conditions prevail for something like 60% of the time.

From our Margam plant we have an easy downgrade of 1 in 330, which would further increase the figure at 20 m.p.h. to 770 ft. We are aware that 12 m.p.h. would not be a suitable speed for shunting fully laden ladles round the blast-furnaces and melting shops, but inefficiency in braking power makes for slow and dangerous working. For increasing ladle capacities with freely running axles, it is becoming increasingly necessary to provide such rolling stock with an adequate braking system, integral with the design, and not added as a cumbersome extra requiring a separate car.

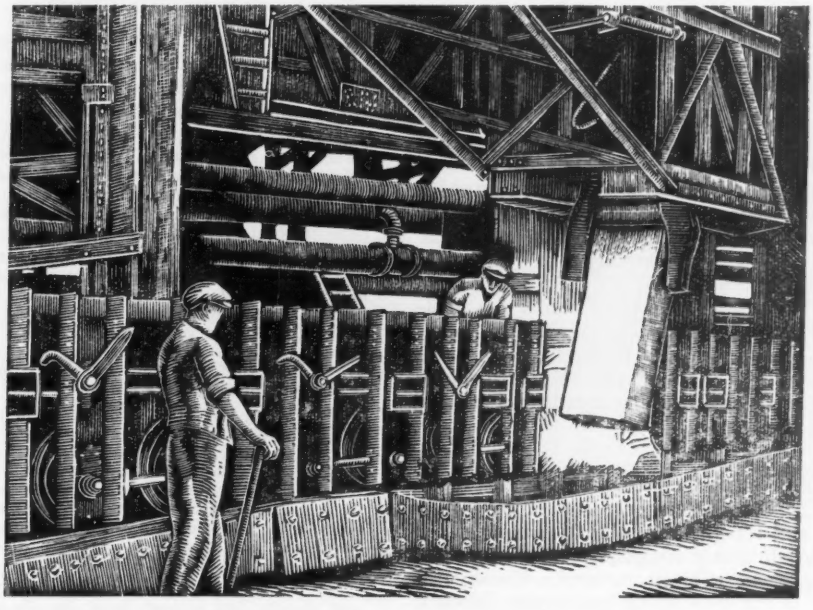
With regard to slag ladles, is it normal practice to have a portable compressor for tipping ladles stationed at the slag dumping point ? What experience has Mr. Stayman had in this matter ? Is is true to say that excessive loads are put on roller bearings due to thrust from the wheel flanges ?

Mr. **D. R. Brown** : Mr. Stock has raised several points on the maintenance of the scale car. This is precisely the kind of detailed information that is helpful to the designer, for the user's experience is essential to the improvement of designs. Mr. Stock's remarks may imply more than he intends, for it is his car which is quoted in the paper as an example of availability and reliability, having served a large furnace continuously for over two years. He can rest assured that full advantage will be taken of his constructive criticism.

On the subject of brakes ; mention is made that these can be fitted and, if users intend to run ladles at 20 m.p.h. downhill, on greasy tracks, they obviously become imperative.

Mr. **T. H. Stayman** : The portable compressor at the site is not a standard fitting, and I know of only one works where one is used. Normally, steam is supplied from the locomotive, and a compressor is used only if there is any danger of being short of air or steam for tipping.

The **Chairman** : There are other questions as well as those relating to the types of rolling stock dealt with in the paper. There is the stock used for handling hot bloom scrap, for example, which would form a very interesting subject of discussion for iron and steel operators.



Charging hot steel ingots into a soaking pit, from the original woodcut by Viva Talbot

Recommendations to Authors

At the Royal Society Scientific Information Conference, held in July 1948, it was recommended that editors of scientific journals should co-operate with abstracting organizations by seeing that each published paper is accompanied by a factual summary suitable for use as an abstract in appropriate journals of abstracts. It was recognized that, although authors' summaries were often unsuitable, their use would appreciably increase the speed of publication and reduce the cost of journals publishing abstracts.

Consideration has now been given to this recommendation, by the Abstracting Services Consultative Committee and the Royal Society Information Services Committee. The latter has received the approval of the Council of the Royal Society for the following recommendations :

(1) It is desirable that every paper appearing in a scientific journal be accompanied by a synopsis, which should be independent of the text and figures, and should preferably appear at the beginning of the paper.

(2) The synopsis should be subject to the same editorial scrutiny and correction as is usual for the full paper. Automatic acceptance of a synopsis written by an author is not desirable.

In endorsing these recommendations the Council of the Royal Society asked that when an author's synopsis is used by abstracting services, this should be clearly indicated in the abstract.

The Publication Committee of The Iron and Steel Institute has also endorsed the recommendations and submits the following suggestions, prepared by the Abstracting Services Consultative Committee, for the guidance of authors.

GUIDE FOR THE PREPARATION OF SYNOPSES

Purpose

It is desirable that each paper be accompanied by a synopsis preferably appearing at the beginning. This synopsis is not part of the paper ; it is intended to convey briefly the content of the paper, to draw attention to all new information and to the main conclusions. It should be factual.

Style of Writing

The synopsis should be written concisely and in normal rather than abbreviated English. It is preferable to use the third person. When possible use standard rather than proprietary terms, and avoid unnecessary contracting.

It should be presumed that the reader has some knowledge of the subject but has not read the paper. The synopsis should therefore be intelligible in itself without reference to the paper ; for example, it should not cite sections or illustrations by their numerical references in the text.

Content

The title of the paper is usually read as part of the synopsis. The opening sentence should be framed accordingly and repetition of the title avoided. If the title is insufficiently comprehensive the opening should indicate the subjects covered. Usually the beginning of a synopsis should state the objective of the investigation.

It is sometimes valuable to indicate the treatment of the subject by such words as : brief, exhaustive, theoretical, etc.

The synopsis should indicate newly observed facts, conclusions of an experiment or argument and, if possible, the essential parts of any new theory, treatment, apparatus, technique, etc.

It should contain the names of any new compound, mineral, species, etc., and any new numerical data, such as physical constants ; if this is not possible it should draw attention to them. It is important to refer to new items and observations, even though some are incidental to the main purpose of the paper ; such information may otherwise be hidden though it is often very useful.

When giving experimental results the synopsis should indicate the methods used ; for new methods the basic principle, range of operation, and degree of accuracy should be given.

Detail of Layout

It is impossible to recommend a standard length for a synopsis. It should, however, be concise and should not normally exceed 200 words.

If it is necessary to refer to earlier work in the summary, the reference should always be given in the same manner as in the text. Otherwise references should be left out.

When a synopsis is completed, the author is urged to revise it carefully, removing redundant words, clarifying obscurities and rectifying errors in copying from the paper. Particular attention should be paid by him to scientific and proper names, numerical data and chemical and mathematical formulae.

SUBMISSION OF PAPERS

This opportunity is taken to remind authors of the requirements of the Publication Committee for the submission of papers for publication in the *Journal of The Iron and Steel Institute*.

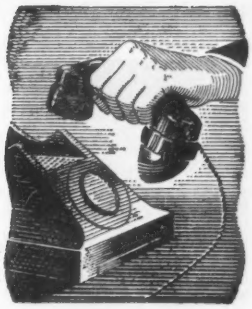
(1) Manuscripts should be typed, in double spacing, on one side of the paper. Duplicated reports, unless printed on non-absorbent paper, cannot be accepted. Mathematical expressions, Greek or other symbols, should be hand written, with ample allowance between typescript matter.

(2) Diagrams should be drawn in black Indian ink on tracing cloth, Bristol board, or stout drawing paper, and generally should be at least twice the size of the final reproduction, which will usually be at column width (3¼ in.) or page width (6¼ in.). All lettering should be written in pencil, either on the original drawing or preferably on a separate print (if a print is possible) or rough sketch.

(3) Photographs (unmounted) should be printed on glossy bromide paper to give sharp contrast. It is helpful to the Editor if authors indicate on the back of the print the important area of the photograph which is to be reproduced, as this enables the block to be made at the smallest size without unnecessary reduction. All diagrams and photographs should be numbered and should be accompanied by a list of captions attached to the manuscript.

(4) Tabular matter should be kept to a minimum and should not repeat data already shown graphically.

N E W S



ANNOUNCEMENTS AND NEWS OF SCIENCE AND INDUSTRY

THE IRON AND STEEL INSTITUTE

Corrosion of Steel

A Joint Meeting of The Iron and Steel Institute and the British Iron and Steel Research Association, to discuss several papers dealing with corrosion and corrosion-fatigue of steel, will be held at 4 Grosvenor Gardens, London, S.W.1, on Tuesday, 18th October, 1949. There will be two sessions, at 10.30 A.M. and at 2.0 P.M. A detailed programme will be given in the September issue of the *Journal*.

Special Lecture

A special lecture on "*Martensitic Transformation*" was delivered by Dr. Morris Cohen, Professor of Metallurgy at the Massachusetts Institute of Technology, Cambridge, U.S.A., at the offices of the Institute, on Tuesday, 5th July, 1949. (See also note on p. 476.)

NEWS OF MEMBERS

▶ Dr. H. J. AXON has been elected to an I.C.I. Fellowship in Metallurgy at the University of Manchester, and will take up the appointment at the beginning of October.

▶ Sir WALTER BENTON JONES, Bt., has been appointed Chairman of the British Association of Coke Oven Tar Producers.

▶ Mr. H. N. BLYTH has left Messrs. L. M. van Moppes and Sons, of North Circular Road, London, N.W.2, to take up an appointment as Lecturer on Ore Dressing at the Imperial College of Science and Technology, Prince Consort Road, London, S.W.7.

▶ Mr. BEN FAIRLESS, of the United Steel Corporation of Delaware, U.S.A., has been awarded the Gary Medal of the American Iron and Steel Institute.

▶ Mr. D. R. GODDARD, Technical Manager at the British American Research, Ltd., of Billington, near Glasgow, has been awarded the Degree of M.Sc. of Birmingham University.

▶ Mr. S. W. HORTON has taken up an appointment as Works Metallurgist at Messrs. Bruntons (Musselburgh) Ltd., of Musselburgh, Scotland.

▶ Dr. A. J. KESTERTON has left Messrs. Dorman, Long and Co., Ltd., to become Melting Shop Manager of the Steel Company of Wales, Ltd., Port Talbot, Glamorganshire.

▶ Mr. O. P. NICHOLSON has left the Borough Polytechnic, London, S.E.1, to take up an appointment as Lecturer in Metallurgy at the Sydney Technical College, Sydney, Australia, under the New South Wales Department of Education.

▶ Miss D. L. PILE, recently Treasurer of Sheet Metal Industries Association, Ltd., has been elected the first woman President of the Birmingham Metallurgical Society. She has joined the staff of the Design and Research Centre of the Gold, Silver, and Jewellery Trades.

▶ Mr. T. G. ROBERTS has left West Hartlepool to take up an appointment as Blast-Furnace Manager at the Barrow Hematite Steel Co., of Barrow-in-Furness.

▶ Mr. D. C. THOMPSON has taken up an appointment with The Electric Furnace Co., Ltd., of Sheffield.

▶ Mr. N. H. TURNER has been appointed Fuel Consultant to The United Steel Companies, Ltd., in addition to his duties at the Appleby-Frodingham Steel Company.

▶ Dr. G. B. WATERHOUSE, Emeritus Professor of Metallurgy at the Massachusetts Institute of Technology, gave the Convocation Address at the Fortieth Assembly of the Nova Scotia Technical College Convocation, held on 6th May, 1949, at Halifax, N.S. An Honorary Degree of Doctor of Engineering was conferred on him on the occasion.

Birthday Honours

▶ Mr. J. E. JAMES (Hon. Vice-President), Chairman of the Lancashire Steel Corporation, has been made a K.B.

▶ Mr. R. M. SHONE, Economic Director of the British Iron and Steel Federation, has received the C.B.E.

▶ Mr. W. B. BAXTER (Vice-President), Director of The United Steel Companies, Ltd., has received the C.B.E.

▶ Mr. F. A. MARTIN, Director of Messrs. Samuel Osborn and Co., Ltd., of Sheffield, has received the O.B.E.

▶ Mr. H. W. SECKER, Technical Adviser on Scrap materials to the Iron and Steel Division of the Ministry of Supply, has received the O.B.E.

▶ Mr. C. A. REED, Works Manager of the Skinningrove Iron Co., Ltd., of Saltburn-by-the-Sea, has received the M.B.E.

Obituary

Major A. B. HOLT CLERKE, C.B.E., R.A. (Retd.), on 13th May, 1949, aged 78.

Mr. P. W. LEE, of Sheffield, on 8th June, 1949.

CONTRIBUTORS TO THE JOURNAL

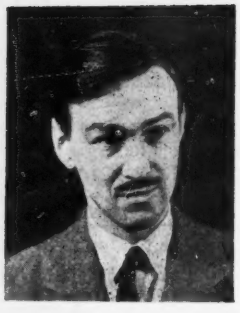
A. R. Philip, M.A.—Research Manager at the Carron Company, Falkirk. Mr. Philip was born in 1915 at Brechin, Angus. He was educated at Brechin High School and the University of Edinburgh, and graduated M.A., with honours in Mathematics and Physics, in 1936. From 1936 to 1939 he was employed in the actuarial department of The Scottish Life Assurance Co. Ltd., Edinburgh. From 1939 to 1946 he was Technical Officer at the Meteorological Office of the Air Ministry. During this period he served for three years as Flight Lieutenant in the R.A.F.V.R. In 1946 he was appointed to Dr. J. H. Chesters' staff, in the Research and Development Department of The United Steel Companies Ltd., and left in 1949 to take up his present position.

Joan D. Tyler—Aerodynamics Section of B.I.S.R.A. Miss Tyler was educated at the Convent of the Holy Family, and trained as laboratory assistant for the Ministry of Supply at Leys School, Cambridge. Miss Tyler has since held posts as laboratory assistant at the Royal Ordnance Factory from 1940 to 1943, on explosive research; at the Farmers' Marketing and Supply, Ltd. Dehydrated Vegetable Laboratory; and at the Enfield

R. S. Howes

Joan D. Tyler

G. Tolley



R. D. Collins

Rifle Laboratory from 1944 to 1946, on powder metallurgy research. She took up her present position in 1946.

R. S. Howes, B.Met.—The Research and Development Department of The United Steel Companies, Ltd., engaged in furnace design under Dr. J. H. Chesters. Mr. Howes was born at Urmston near Manchester. He was educated at King Edward VII School, Sheffield, and at Sheffield University, and graduated with B.Met. in 1943. He was technical assistant in the Siemens melting shop of Messrs. Samuel Fox and Co., Ltd., until the end of 1944, and was then assistant metallurgist at the Ministry of Supply Works at Barrow. Mr. Howes took up his present position in 1947.

G. Tolley, M.Sc.—Chief Chemist to Metallisation, Ltd. Mr. Tolley was born in 1925. He was educated at Halesowen Grammar School, and during 1940 to 1945 he was at the Central Technical College, Birmingham (part time). During the latter part of this period he occupied various positions in several laboratories, including nearly three years with the (then) Corrosion Committee of the Iron and Steel Institute. In 1945 he obtained the degree of B.Sc. (London External). with first-class honours in Chemistry. In 1948 he was awarded M.Sc. (London) for studies on the catalytic oxidation of sulphur dioxide on metal surfaces. He took up his present position in 1947. Mr. Tolley was elected Rotary Foundation Fellow for 1949 to 1950, under the terms of which he will take up studies at Princeton University, U.S.A.

R. D. Collins, B.Sc.—In the Aerodynamics Section of the Physics Department of the British Iron and Steel Research Association. Mr. Collins was educated at Dulwich College and University College, London, and graduated in Physics in 1942. From 1942 to 1946 he served in R.E.M.E. He took up his present position in 1947.

IRON AND STEEL ENGINEERS GROUP

The ELEVENTH MEETING of the Iron and Steel Engineers Group will be held at the offices of the Institute, 4 Grosvenor Gardens, London, S.W.1, on Wednesday, 23rd November, 1949. The details of the papers to be discussed will be given in future issues of the *Journal*.

AFFILIATED LOCAL SOCIETIES

Sheffield Society of Engineers and Metallurgists

A special Joint Meeting of the Society and the Sheffield Metallurgical Association was held at the Royal Victoria Station Hotel, Sheffield, on Friday, 1st July, 1949. Professor M. Cohen, of the Massachusetts Institute of Technology, Cambridge, U.S.A., delivered a lecture on "*The Principles of the Hardening and Tempering of Steel.*" (See also note on p. 475.) A précis of the lecture is to be published in "*Metallurgia.*"

Ebbw Vale Metallurgical Society

The List of Officers for the session 1949-50 is as follows :

Chairman

R. C. POWELL, B.Sc.

Vice-Chairman and Hon. Treasurer

J. H. STEELE

Joint Hon. Secretaries

F. W. LEWIS — E. G. BRACE

Committee

J. BEESE	W. LEWIS
W. H. R. BIRD, M.A., B.Sc.	F. LLEWELLYN
G. CAMPBELL	A. J. MEO
W. J. DAVIES	H. MICHAEL
A. ELLIS	H. PADBURY
*R. A. HACKING, O.B.E., M.Sc.	F. PROBYN
E. HEMINGWAY JONES	W. J. S. ROBERTS, B.Sc.
W. D. JENKINS, B.Sc.	J. SMITH

W. B. WILLIAMS

* Representing The Iron and Steel Institute.

INSTITUTE OF METALS

Annual May Lecture

The Annual May Lecture of the Institute of Metals was delivered by Sir Edward Appleton, F.R.S., on Wednesday, 25th May, 1949, at the Royal Geographical Society.

Sir Edward, who recently relinquished his post as Secretary of the Department of Scientific and Industrial Research, described the history, organization, and work of the Department. He said that we must look to the Research Associations for the greatest contribution towards increased productivity. He referred to the record output by the cast iron industry of a million more tons per annum than in pre-war years, which could be attributed largely to the work of its Research Association, resulting in the redesign of the cupola furnace and in the long list of new heat-resisting and corrosion-resisting cast irons, including the remarkable cast iron of great strength known as nodular cast iron.

As an example of successful co-operation between the Government, two Research Associations, and a number of industrial firms, which might well result in an extra million tons of steel a year being produced from existing open-hearth plant, Sir Edward mentioned the successful production in Government factories of magnesite from magnesia extracted from sea water, from which basic

refractory bricks can be manufactured, in every way as good as those made from imported materials. Under the auspices of the British Iron and Steel Research Association and the British Ceramics Research Association several open-hearth furnaces of 'all basic' construction have been built of these bricks and are giving an increased output of 10% per square foot of hearth. Although more expensive than those in general use, these bricks enable the furnace to be driven at a higher temperature, and give it longer life, which makes a continuous working week possible.

Commenting on the D.S.I.R. policy of grants given to individual workers engaged on specific items of research judged to be of timeliness and promise, Sir Edward said that the research trainees need not necessarily work at a University; grants may be given by the Department for training in applied science, in the methods of industrial research, and for courses in technology; and the awards may be held at technical colleges, D.S.I.R. Establishments, Research Associations, and, in fact, at any research laboratory or institution approved by the Advisory Council, including, in special cases, industrial works.

Honorary Corresponding Members

The Council of the Institute of Metals has appointed the following members to be Honorary Corresponding Members of the Council for their respective countries:

Spain	Professor J. ORLAND, M.Sc., M.A., Ph.D., D.D., Professor and Chief of the Department of Metallography and Strength of Materials, Instituto Católico de Artes e Industrias, Madrid.
Sweden	Professor A. G. E. HULTGREN, Professor of Metallography, Tekniska Högskolan, Stockholm. (Additional Honorary Corresponding Member).
United States of America	Professor R. F. MEHL, B.S., Ph.D., Hon.Eng.D., Hon.Sc.D., Director of the Metals Research Laboratory and Head of the Department of Metallurgical Engineering, Carnegie Institute of Technology, Pittsburgh, Pa. (Additional Honorary Corresponding Member). Dr. R. A. WILKINS, Vice-President, Research and Development, Revere Copper and Brass, Inc., Rome, N.Y. (Additional Honorary Corresponding Member).

NEWS OF SCIENCE AND INDUSTRY

Radium and Radon for Industrial Radiography

The Ministry of Supply has announced that the Government-owned Radiochemical Centre at Amersham can now accept orders for radium and radon as sources of gamma rays for use in industrial radiography.

Although the gamma rays associated with radium and radon are of identical quality, the elements have characteristic properties which distinguish them, from the radiographic point of view:

(i) The intensity of radiation from radium may, for practical purposes, be regarded as constant, whereas that from radon decreases continually, falling to half its initial value in 3·8 days, and thereafter being halved in each succeeding similar period.

(ii) The volume of one gramme of radium sulphate, which is the radium salt commonly used for radiographic purposes, is roughly 0·5 c.c. On the other hand, the volume of a quantity of radon equivalent in gamma radiation to one gramme of radium sulphate need not exceed a few cubic millimetres.

For radiographs of equal resolution, radon can be used much closer to the object than radium, with a corresponding reduction in the exposure time. Thus, in some circumstances accessibility, distance, and speed factors favour the use of radon.

Applications for radium and radon for industrial use should be addressed to: The Radiochemical Centre, White Lion Road, Amersham, Bucks., with a detailed specification of the capsule required. Consultation with the Centre will be necessary to ensure that technical requirements are met.

Research Fellowship in Metallurgy

The Royal Society, and the Armourers and Brasiers' Company have opened a Research Fellowship in Metallurgy for research which must be connected with base metals and alloys, and preferentially those used in connection with the Ancient Crafts of the Company of Armourers and Brasiers. The research is to be carried out under the scheme approved by the Royal Society and the Armourers and Brasiers' Company. The appointment will be for two years in the first instance but may subsequently be extended to a maximum of five years. The stipend will be £850 per annum with superannuation benefit.

MEMOIRS

David Rees Percy Williams (known as Percy Williams) died on 12th December, 1948. Mr. Williams was born at Middlesbrough, Yorks, in 1879. He was educated at the High School, Middlesbrough. On leaving school he was articled to a solicitor, but left to enter the steel trade, as did his father, who was for many years a steel rolling-mill manager at the Dowlais Iron Co., Ltd., Glamorganshire.

Mr. Williams served his apprenticeship in the roll-lathe house at the Dowlais Iron Co., Ltd. In 1904 the family returned to Middlesbrough, and Mr. Williams became chief roll designer at Messrs. Dorman, Long and Co., Ltd. In 1905 he started up the new works of the Cargo Fleet Iron Co., Ltd., at Middlesbrough, and later became Mill Manager. In 1919 he was appointed Assistant Works Manager at Messrs. Wm. Beardmore and Co., Ltd. at Mossend, Lanarkshire. In 1929 he became Works Manager at the Dowlais Iron and Steel Works of Messrs. Guest Keen and Nettlefolds, Ltd. In 1934 he went to the Cardiff works of Messrs. Guest Keen Baldwins, Ltd., as General Works Manager, and superintended the erection of their modern works there, which started operation in 1936.

In 1943 Mr. Williams retired to Newcastle Emlyn, Carmarthenshire, where he took a great interest in the social life of the district. He became Chairman of the Angling Association, and also of the local branch of St. John's Ambulance. Mr. Williams became a Member of The Iron and Steel Institute in 1920.

John Henry Monypenny, F.Inst.P., L.I.M. died on 2nd March, 1949. Mr. Monypenny was born in Sheffield in 1885. He was educated at the Royal Grammar School in Sheffield, and in 1901 he gained a technical scholarship to what was then known as the Metallurgical Department of University College, Sheffield. In addition to his metallurgical training under Professor J. O. Arnold, Mr. Monypenny gained scientific knowledge under Professor Hicks of the Department of Physics. In 1904 he obtained the Associateship in Metallurgy, and was awarded the Mappin Medal. In the same year he was appointed Chief of the Research Laboratory of Messrs. Brown Bayley's Steel Works in Sheffield, and in 1928 he became their Technical Representative. He retired in 1945.

With the discovery of stainless steel, Mr. Monypenny built up a unique reputation in England, Germany, and particularly in the United States of America. He wrote a series of articles on stainless steels and their application, and in 1926 he published his book "*Stainless Iron and Steel*," which will long be regarded as a metallurgical classic. It may have been a national loss when, in 1928, he transferred from this scientific investigation for which he was so eminently suited, to more commercial concerns, but the loss to science may have been counterbalanced by the gain to industry.

During the remainder of his life his main activities were in collaborating with the chemical engineer on the uses of stainless materials.

Mr. Monypenny was an invalid for the last three years of his life, but was able during that time to complete an extensively revised edition of his book, "*Stainless Iron and Steel*."

Mr. Monypenny was a Fellow of the Institute of Physics, and of the Institution of Metallurgists. He was a member of The Iron and Steel Institute for forty-two years ; and he also served on Corrosion and Alloy Steels Research Committees. He was a Member of the Institute of Metals, and served as Chairman of the Sheffield Local Section from 1927 to 1929. For some years he served on the Council of the Faraday Society, and from 1935 to 1938 he was Chairman of the British Chemical Plant Manufacturers' Association. He was also a Member of the Society of Chemical Industry, and of the American Institute of Mining and Metallurgical Engineers, and of the American Society for Metals. In 1946 he was awarded the Silver Medal of the Institute of Marine Engineers for a paper on "Stainless Steel for Turbine Blading."

Despite an exceptionally busy professional life, Mr. Monypenny found relaxation in music : he was an accomplished pianist and organist.

F. C. THOMPSON

William Frederick Rowden died on 16th March, 1949. Mr. Rowden was born on 30th May, 1897. He was with Messrs. Armstrong Whitworth in his early days, both at Newcastle and at Openshaw, and left to join Messrs. High Speed Alloys, Ltd., Widnes. In April 1937 he became a member of the staff of the Development and Research Department of The Mond Nickel Co., Ltd., and left at the end of 1938 to join the Climax Molybdenum Company of Europe, Ltd., becoming European Director of that company in 1939. During the late war he rendered valuable service as a Metallurgical Adviser to the Department of Tank Design of the Ministry of Supply.

Mr. Rowden became a Member of The Iron and Steel Institute in 1933 ; he was also a Member of The Institute of Metals, the Institute of British Foundrymen, the Institute of Welding, the Manchester Association of Engineers, and the Manchester Metallurgical Society.

Major Augustus Basil Holt Clerke, C.B.E., M.I.Mech.E., M.I.S.I., R.A. (Retd.), died on 13th May, 1949, at the age of 78. Major Clerke was a member of the Institute for the past 37 years and he gave valued support to the work of the Institute. Born in 1871, son of the late Colonel Shadwell H. Clerke, he was educated at Cheltenham, and subsequently passed into the Royal Military Academy, Woolwich. He was gazetted 2nd Lieut. in the Royal Artillery in 1889, and after Regimental Service became Assistant Inspector of Steel in 1899, and subsequently Chief Instructor at the Ordnance College in 1906, when he attained the rank of Major. Then followed a short period of service in India where he commanded the 19th Battery, Royal Field Artillery, after which he returned to Woolwich as Inspector in the Armaments Inspection Department in 1908, and retired from the Service in 1911.

Later that year Major Clerke joined Messrs. Hadfields Ltd., of Sheffield, to take charge of the company's extensive Ordnance Department. He was made a Director in 1913, and became Joint Managing Director in 1917. On the death of Sir Robert A. Hadfield, Bt., in 1940, he was appointed Deputy Chairman of the company, and retained that position until his retirement from active business in 1945.

During the war of 1914–1918, Major Clerke was a valued member of the Sheffield Joint Works Committee, and ably assisted in increasing the output of munitions from the city, work which was recognized by the award of the C.B.E. in 1918.

Major Clerke was responsible for notable improvements in heavy armour-piercing projectiles ; in particular, his invention of the relieved adaptor, now a standard feature of heavy-calibre projectiles, solved the problem of the unbroken penetration of armour and had a profound effect on naval gunnery.

DIARY

16th—27th Aug.—CAMBRIDGE SUMMER SCHOOL IN ELECTRON MICROSCOPY—Cavendish Laboratory, Cambridge.

17th Aug.–6th Sept.—UNITED NATIONS SCIENTIFIC CONFERENCE on "The Conservation and Utilization of Resources "—Lake Success, U.S.A.

25th Aug.–10th Sept.—SHIPPING, ENGINEERING AND MACHINERY EXHIBITION, Olympia, London, W.14.

28th–29th August—SVERIGES GJUTMÄSTAREFÖRBUND GJUTERITEKNISK FÖRENING—Forty-First Annual Meeting—Gävle, Sandviken, Sweden.

29th Aug.–2nd Sept.—INTERNATIONAL FOUNDRY CONGRESS—Amsterdam, Holland.

31st Aug.–7th Sept.—BRITISH ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE—Annual Meeting—Newcastle-upon-Tyne.

5th–7th Sept.—FOURTH NORWEGIAN ENGINEERS CONFERENCE—Seventy-fifth Anniversary of the Norwegian Engineers Association—Oslo.

TRANSLATION SERVICE

(The previous announcement was made in the July, 1949, issue of the *Journal*, p. 350.)

TRANSLATION AVAILABLE

No. 381 (Russian). M. I. KOROBOVA and N. I. KOROBOV : "Catalytic Agents for the Reduction Process in Blast-Furnaces." (*Bulletin de l'Académie des Sciences, U.R.S.S., Classe des Sciences Techniques*, 1946, No. 4, pp. 567–577).

TRANSLATION IN COURSE OF PREPARATION

(German). W. ROTH : "The Cooling of an Ingot in 'Water-Casting.'" (*Aluminium*, 1943, vol. 25, July–Aug., pp. 283–291).

(Russian). A. N. TIKHONOV and E. G. SHOIDOVSKI : "The Theory of Continuous Casting." (*Journal of Technical Physics*, U.S.S.R., 1947, vol. 17, No. 2, pp. 161–176).

CHARGES FOR COPIES OF TRANSLATIONS.—The charge for the above translations is £1 for the first copy and 10*s*. for each additional copy of the same translation. Requests should be accompanied by a remittance. These translations are not available on loan from the Joint Library.

TRANSLATIONS PREPARED AT MEMBERS' REQUEST.—Members requiring translations of foreign papers are invited to communicate with the Secretary, who will ascertain whether the translations can be prepared for inclusion in the Series.

ABSTRACTS OF CURRENT LITERATURE *and* BOOK NOTICES

IRON AND STEEL MANUFACTURE AND RELATED SUBJECTS

CONTENTS

	PAGE
Fuel—Preparation, Properties, and Uses	479
Blast-Furnace Practice and the Production of Pig Iron	479
Treatment and Use of Slags	480
Production of Steel	480
Foundry Practice	481
Heating Furnaces and Soaking Pits	482
Heat-Treatment and Heat-Treatment Furnaces	482
Forging, Stamping, Drawing, and Pressing	483
Rolling-Mill Practice	483
Welding and Flame-Cutting	484
Machining and Machinability	485
Powder Metallurgy	485
Properties and Tests	486
Metallography	489
Corrosion	490
Analysis	490
Economics and Statistics	492
Book Notices	493
New Publications	496

FUEL—PREPARATION, PROPERTIES, AND USES

Training in Combustion Fundamentals. B. Dagan. (American Institute of Mining and Metallurgical Engineers. Proceedings of the 31st National Open Hearth Conference, Apr., 1948, pp. 68–69). An outline is given of the programme for instructing open-hearth furnace operators in combustion and fuel control which has been established at the Kaiser plant, Fontana, California.—R. A. R.

The Lines on which the Production of Thermal Energy is Developing. O. Martin. (Stahl und Eisen, 1949, vol. 69, Jan. 20, pp. 40–48). The present state of development of stationary energy producers, particularly steam plants, is discussed and an attempt is made to assess the competitive possibilities of the gas turbine. The problem of the immediate future is the development of a gas-turbine-driven blower to work in conjunction with a metal-tube heat exchanger for producing hot blast. Steam power is likely to be retained for electricity production.—R. A. R.

Coal Preparation for Steelmaking. N. L. Davis. (Iron and Steel Engineer, 1949, vol. 26, Mar., pp. 79–84). The author outlines the theory of the heavy-media suspension process and shows the advantages of its application in coal cleaning plants. It enables mechanically mined coal to be adequately and efficiently cleaned for steelmaking purposes.

J. C. R.

Coke Oven Machinery. R. Berg. (Yearly Proceedings of the Association of Iron and Steel Engineers, 1948, pp. 286–294). *See* Journ. I. and S.I., 1948, vol. 159, July, p. 322.

Dry Cooling of Incandescent Coke in Coking Plants and Gas Works. W. Hersche. (Monats-Bulletin, Schweizerischer Verein von Gas- und Wasserfachmännern, 1948, vol. 28, May, pp. 113–118; June, pp. 150–154: [Abstract) Chimie et Industrie, 1949, vol. 61, Feb., p. 149).

The Control of Gas Producer Operation. G. Engels. (Stahl und Eisen, 1949, vol. 69, Jan. 6, pp. 24–25; Jan. 20, pp. 54–55). As there is difficulty under the present conditions in Germany, in referring to the literature, and as gas-producer practice requires further improvement, the author reviews the literature on improvements and makes recommendations.—R. A. R.

BLAST-FURNACE PRACTICE AND THE PRODUCTION OF PIG IRON

Blast Furnaces in the U.S.S.R. E. Mazanek. (Hutnik, 1948, vol. 15, Oct.–Nov., pp. 461–467). [In Polish]. The development of blast-furnaces in the U.S.S.R. is considered. Some examples of standard types of blast-furnace are given with dimensions and production data on charges and output. Data on the linings are also presented.—W. J. W.

The "HUTA POKÓJ" Phosphoric Steel Process. A. Dagnan. (Hutnik, 1948, vol. 15, Dec., pp. 528–535). [In Polish]. A process is described in which phosphoric pig iron (P~2%) was used so as to reduce the proportion of scrap in the charge. A phosphorus-rich slag for use in agriculture has been developed. The problem is analysed from the theoretical and economic points of view, and the process is shown to be profitable. The high phosphorus process reduces the amount of imported scrap and this is of great importance.

W. J. W.

Notes on Modern Blast Furnace Technique. M. Brun and M. Legendre. (Métallurgie, 1948, vol. 80, Sept., pp. 7–9; Oct., pp. 15–17; Dec., pp. 15, 17–18; 1949, vol. 81, Jan., pp. 13–15, 17–18; Mar., pp. 15–17, 19; Apr., pp. 15–18). This is a continuation of a series of articles (*see* Journ. I. and S.I., 1948, vol. 159, July, p. 324 and vol. 160, Nov., p. 322). In the present parts the authors deal with the tapping of iron from the blast-furnace, the use of blowers, and the cleaning of blast-furnace gas. Descriptions are included of pig-casting machines, clay guns, mixers, and ladles.—J. C. R.

Contribution on the Metallurgy of the Blast-Furnace. W. Oelsen and H. Maetz. (Stahl und Eisen, 1949, vol 69, Mar. 3, pp. 147–153). After discussing the necessity of taking into account the degree of reduction when evaluating laboratory tests on the desulphurization of pig iron, the authors consider the most important reduction reactions occurring under various physical conditions. It is found that at temperatures up to about 1550° C. the reactions between liquid pig iron and liquid slag do not proceed so far as when mixed powders are heated at lower temperatures in the solid or semi-fluid state. In the liquid phase the reduction does not reach a high rate until temperatures exceeding 1600° C. are attained. Relationships affecting the reduction processes are given, laboratory tests relating to them are reported, and the possibility of applying laboratory results to full-scale plant is dealt with.—R. A. R.

A Brief History of Electric Pig-Iron Smelting in Norway. H. Christiansen, jun. (Journal of The Iron and Steel Institute, 1949, vol. 162, May, pp. 11–12). The first electric pig-iron furnace in Norway was erected in 1910. The first Tysland furnace came into operation in 1924 and was modified by I. Hole in 1927; it was dismantled in 1948, having worked very successfully. A new iron and steel works with three or four Tysland-Hole furnaces is to be built at Mo i Rana.—R. A. R.

The Use of Anthracite from La Thuile in "Electrometall" Furnaces for Iron Smelting. C. Ricchi. (Metallurgia Italiana, 1949, vol. 41, Jan.–Feb., pp. 23–31). Reports are given of the operation of an Electrometall smelting furnace at the Stabilimenti Elettrosiderurgici of Aosta, where, during the summer campaign of 1925, some smelting tests were

carried out with magnetite from Cogne, anthracite from La Thuile, and charcoal. The operation of this furnace with anthracite is described with notes on the composition of slags and the thermal balance, and a comparison is made with a modern three-phase low-shaft furnace.—R. F. F.

TREATMENT AND USE OF SLAGS

The Structural Components of the Iron Oxide Silicates in the Slags from High- and Low-Shaft Bloomery Furnaces, and the Mechanism of the Separation of Metallic Iron from such Slags. B. Neumann and H. Klemm. (Archiv für Metallkunde, 1949, vol. 3, Jan., pp. 7–11).

Artificial Mineral Fibres for Thermal Insulation Purposes. K. Seiffert. (Zeitschrift des Vereines deutscher Ingenieure, 1949, vol. 91, Apr. 1, pp. 149–153). The raw materials and processes for manufacturing insulating materials for industrial furnaces and boilers from slag and glass are described and data on their bulk density and thermal conductivity at different temperatures are presented.—R. A. R.

Sulphated Hydraulic Slag Cements. P. P. Budnikov. (Bulletin de l'Académie des Sciences de l'U.R.S.S., 1948, No. 3, p. 423: British Ceramic Abstracts, 1948, July–Aug., p. 250A). Acid open-hearth slags can be mixed with portland cement to produce lime-slag and gyysum-slag cements. In the latter case the slag reacts with the gypsum, and portland cement or slaked lime is added as an alkali component. Cement produced by this method, however, has poor mechanical qualities. Sulphated cement with good stability can nevertheless be produced from open-hearth slag by activating it with calcium sulphate (especially anhydrite) and a mixture of CaO and MgO. In place of the latter components it is possible to use dolomite, burnt at 1000° to 1100° C.

PRODUCTION OF STEEL

Recent Developments in the Steel Industry. C. H. Desch. (Proceedings of the Royal Institution of Great Britain, 1947, vol. 39, Part I, pp. 127–136). *See* Journ. I. and S.I., 1948, vol. 160, Oct., p. 220.

A New 170-Ton Open-Hearth. I. E. Voet. (Iron and Steel Engineer, 1949, vol. 26, Feb., p. 112). A brief description is given, with dimensions, of the new 170-ton open-hearth furnace of Koninklijke Nederlandsche Hoogovens en Staalfabrieken N.V., Ijmuiden, Holland.—J. C. R.

Review of Furnace Maintenance. M. J. Miller. (American Institute of Mining and Metallurgical Engineers, Proceedings of the 31st National Open Hearth Conference, Apr., 1948, pp. 60–65). Data on time spent in open-hearth bottom repairs are presented and discussed. Delays for repairs between heats seem to be greater in summer than in winter.—R. A. R.

Practices Affecting Yields and Surface Quality of Rimmed and Semikilled Steel. L. R. Silliman. (American Institute of Mining and Metallurgical Engineers, Proceedings of the 31st National Open-Hearth Conference, Apr., 1948, pp. 14–26). *See* Journ. I. and S.I., 1948, vol. 160, Sept., p. 104.

Increasing Firing Rates. H. S. Hall. (American Institute of Mining and Metallurgical Engineers, Proceedings of the 31st Open Hearth Conference, Apr., 1948, pp. 66–68). Methods of efficiently using fuel oil for heating open-hearth furnaces are described. The quantity of steam for atomizing ranges between 2½ and 3¼ lb. per U.S. gal. of oil, and the steam temperature is in the 500–600° F. range.—R. A. R.

Factors Affecting Basic Open-Hearth Operating Rates. O. Pearson. (American Institute of Mining and Metallurgical Engineers, Proceedings of the 31st National Open Hearth Conference, Apr., 1948, pp. 74–87). Factors affecting total heat time when producing steel from high-scrap charges (39% hot metal, 56% scrap) and high-hot-metal charges (57% hot metal, 33% scrap) were studied in a melting shop with fourteen 145-ton open-hearth furnaces. The recommendations are: (*a*) Every effort should be made to keep the scrap charged below 84 boxes (27 cu. ft. each) per heat. (*b*) In high hot-metal charges the cold iron should not exceed 10% of the total charge. (*c*) The average carbon in the charge should not exceed that desired at tapping by more than 0·65%. (*d*) Lime additions should be as small as possible. (*e*) Pit scrap should be charged in small pieces. (*f*) Hot metal charged should not have more than 0·045% of sulphur.—R. A. R.

Use of Oxygen (or Compressed Air) in the Open-Hearth Furnace. F. G. Norris. (American Institute of Mining and Metallurgical Engineers, Proceedings of the 31st National Open Hearth Conference, Apr., 1948, pp. 35–42: Industrial Heating, 1949, vol. 16, Feb., pp. 272–276). Experience in the use of oxygen by the Wheeling Steel Corp. is reported. A bare iron pipe, ¾ in. in dia., is used with oxygen at a pressure of 75–80 lb./sq. in. at the lance, the flow being about 30,000 cu. ft./hr. Time consumed in furnace bottom repairs was not increased when injecting oxygen. There was no improvement in the quality of the steel with direct oxidation, but less skull was formed, which led to an indirect improvement. Trials in the use of oxygen to desiliconize iron in the blast-furnace ladle were not successful, as the ladle lining was cut rapidly, excessive amounts of siliceous slag and objectionable fumes were formed, and the yield was low.—R. A. R.

Oxygen as a Factor in Combustion of Fuel in the Open Hearth Furnace. D. D. Howat. (Journal of the West of Scotland Iron and Steel Institute, 1947–48, vol. 55, pp. 176–221). The theory and practice of the use of oxygen in the open-hearth furnace are considered. Calculations indicate that at 1675–1700° C. an increase of 15% in the net heat to the steel bath may be secured with a rise of 35–50° C. in the roof temperature. The calculations demonstrate the substantial thermal advantage resulting from the employment of unheated mixtures containing only 40% of oxygen; this opens up the possibility of eliminating the regenerator system. The advantages of using oxygen mixtures are much more limited with low grade fuels than with high grade fuels, so that greater benefits are indicated by using oxygen in the gasification process in addition to the combustion process. The practical and economic problems in the employment of oxygen mixtures appear formidable. They include the development of waste-heat boilers capable of dealing with gases at 1600° C.—R. A. R.

Use of Oxygen in Hot Metal for Agitation of the Bath. H. E. Warren, jun. (American Institute of Mining and Metallurgical Engineers, Proceedings of the 31st National Open Hearth Conference, Apr., 1948, pp. 27–35). An account is given of experience gained by the Carnegie-Illinois Steel Corp. in the use of oxygen injected into the bath. The general conclusions include: (1) A multiple-hole jet with the same or greater flow of oxygen causes less splash than a single-hole jet, and is probably less harmful to the roof; (2) the higher the carbon when oxygen injection is commenced, the faster is the rate of carbon removal; (3) carbon can be removed at the rate of 0·0237%/min., but the average rate is 0·015%/min.; (4) heats have been made with 0·95 cu. ft. of oxygen/net-ton/point of carbon; and (5) no detrimental effect on the quality of the steel has been observed.—R. A. R.

Operation of Oxygen-Enriched Open-Hearth Furnaces. J. S. Marsh. (American Institute of Mining and Metallurgical Engineers, Proceedings of the 31st National Open Hearth Conference, Apr., 1948, pp. 43–56). *See* Journ. I. and S. I. 1949, vol. 161, Jan., p. 58.

Oxygen through the Burner at Granite City Steel Company's Plant. R. C. Solomon. (American Institute of Mining and Metallurgical Engineers, Proceedings of the 31st National Open Hearth Conference, Apr., 1948, pp. 88–90). Data are presented on the results obtained by introducing oxygen through a ½-in. tube 5 in. below the fuel oil pipe of a 68-ton open-hearth furnace fired with 80% fuel oil and 20% natural gas. The conclusions are tentative, as only 100 heats have been run. With 30% hot-metal charges production increased 38·2%, with a 21·6% decrease in fuel consumption. With a 25% cold-pig-iron charge production increased 17·5%, with an 18% decrease in fuel consumption. The use of oxygen during one campaign shortened the roof life by 35%.—R. A. R.

Metallurgical Oxygen in Cold-Metal Shops. L. L. Whitney. (American Institute of Mining and Metallurgical Engineers, Proceedings of the 31st National Open Hearth Conference, Apr., 1948, pp. 91–96). Results obtained by introducing oxygen through a 1-in. pipeline at a pressure of 95–100 lb./sq. in. and at velocities up to 9000 cu. ft./hr. into a 30-ton open-hearth furnace are presented and discussed. A double fuel-oil burner was designed; both burners were employed with oxygen during melt-down, but only one during refining. Conclusions after a campaign of 400 heats were: (1) Melting costs were less than in previous campaigns, so that it might be economic to operate with oxygen when production demands decrease. (2) Checker-chamber temperatures increased from

300° to 400° F. and 75% more steam was produced by the waste-heat boiler. (3) Refractory costs decreased. (4) There was less choking of slag pockets, checkers, and flues. (5) The quality of the steel was unchanged. (6) The bath temperature was increased. (7) Sulphur in the fuel oil was burned in the flame.—R. A. R.

Use of Oxygen for Carbon Reduction in Cold-Metal Practice. H. M. Parker. (American Institute of Mining and Metallurgical Engineers, Proceedings of the 31st National Open Hearth Conference, Apr., 1948, pp. 96–97). Experience in the use of oxygen for decarbonizing heats at the works of the Armco Steel Corp. is reported. The consumption is 41·5 cu. ft. per ton of ingots. It is injected through 1-in. pipes which are consumed at the rate of 1½ ft./min. when the carbon in the steel is in the 0·05–0·10% range. Oxygen is particularly advantageous when producing low carbon steel from an all-cold charge.—R. A. R.

Compressed Air Used at Granite City. F. von Gruenigen. (American Institute of Mining and Metallurgical Engineers, Proceedings of the 31st National Open Hearth Conference, Apr., 1948, pp. 98–100). A comparison is made of three methods of decarburizing open-hearth furnace heats, namely, with ore only, with compressed air only, and with ore and compressed air. The air was injected at the slag-metal interface through a ¾-in. pipe at 90 lb./sq. in. Ore plus air led to a vigorous boil and showed a saving of 15% in the amount of ore required. The use of air reduced the heat time by only 3 min. on the average, but it was advantageous in cases where the carbon at melt-down was so low that ore was not normally added. No appreciable difference in the properties of the steel produced was noted.—R. A. R.

Use of Compressed Air for Carbon Reduction at Colorado Fuel and Iron Company. W. H. Carpenter. (American Institute of Mining and Metallurgical Engineers, Proceedings of the 31st National Open Hearth Conference, Apr., 1948, pp. 100–101). Experience in the use of air injection into the open-hearth bath is reported. Best results were obtained when additions were made just before injecting air. It is considered that the increase in the rate of carbon removal is due to the agitation of the bath rather than to the oxygen in the air.—R. A. R.

Methods of Improving Furnace Charging.—R. R. Fayles. (American Institute of Mining and Metallurgical Engineers, Proceedings of the 31st National Open Hearth Conference, Apr., 1948, pp. 102–113). An account is given of the scrap preparation and charging methods at the Lukens Steel Company's plant. Thin-legged frames to the furnace doors give wide openings and charging boxes 37 in. wide can be used through a frame opening. On three furnaces the centre doors are 6 ft. 6 in. wide. Good scrap-yard supervision is the most important factor in scrap preparation.—R. A. R.

Use of Multiple Burners and Compressed Air to Improve Operating Rates of Open-Hearth Furnaces. U. F. Corsini. (American Institute of Mining and Metallurgical Engineers, Proceedings of the 31st National Open Hearth Conference, Apr., 1948, pp. 70–74). In order to increase the melting rate of a 100-ton oil-fired open-hearth furnace when the steam pressure for atomizing could not be increased, a second burner was fitted above the original one. The results of firing trials with the two-burner system were an increase of 0·48 net tons (5·1%) of metal melted per hour, with a consumption of 1·54 U.S. gal. of oil per ton. The introduction of compressed air through a 1-in. pipe below the burners was tried on both single and double burner furnaces and found to be an improvement, so that all four furnaces in the melting shop have been converted to two burners with compressed air underneath.—R. A. R.

Heating Open-Hearth Furnaces. J. J. Hazel. (American Institute of Mining and Metallurgical Engineers, Proceedings of the 31st National Open Hearth Conference, Apr., 1948, pp. 156–159). Factors affecting the life of open-hearth furnace linings are discussed. A controlled rate of heating is advocated and the practice of taking 48 hours to bring the furnace up to temperature has been introduced by the Republic Steel Corp.—R. A. R.

Surface and Yield of Fully Aluminium-Killed Deep-Drawing Steels. C. W. Conn. (American Institute of Mining and Metallurgical Engineers, Proceedings of the 31st National Open Hearth Conference, Apr., 1948, pp. 181–183). The method of adding aluminium to steel adopted by the Ford Motor Co. is described and its effect on surface condition and inclusions is discussed. Aluminium in stick form is added in the ladle (2½ lb./ton. of steel) and 1½ lb. in shot form per ton of steel in the mould.—R. A. R.

Fully Aluminium-Killed Deep-Drawing Steels. W. E. Bayers, jun. (American Institute of Mining and Metallurgical Engineers, Proceedings of the 31st National Open Hearth Conference, Apr., 1948, pp. 184–187). Aluminium and cryolite additions to steel and surface defects are discussed. The practices of adding 4 lb. of aluminium per ton of steel in the ladle, and 1·3 lb. in the ladle with 2·5 lb. in the mould have proved satisfactory, and additions of cryolite in the mould have resulted in fewer surface defects. R. A. R.

Defects in Fully Aluminium-Killed Deep-Drawing Steel. G. L. Plimpton. (American Institute of Mining and Metallurgical Engineers, Proceedings of the 31st National Open Hearth Conference, Apr., 1948, pp. 187–189). Pouring temperatures above 3000° F. are associated with a high incidence of cracking during the rolling of aluminium-killed steel. Ingots fairly high in aluminium (over 0·070%) were better than those with less aluminium, whilst a slight increase in the sulphur content considerably increased crack formation.—R. A. R.

Sulphur Elimination in Cold-Metal Basic Open-Hearth Practice. C. W. Briggs. (American Institute of Mining and Metallurgical Engineers, Proceedings of the 31st National Open Hearth Conference, Apr., 1948, pp. 114–120). The replies to a questionnaire on melting practice with special reference to keeping down the sulphur, sent in by 12 works operating open-hearth furnaces with 100% cold-metal charges are analysed. When the sulphur is high, the corrective additions of lime should be started as early as possible, because the lower FeO level prevailing during the earlier higher-carbon stages of the heat favours the removal of sulphur. Data on the effects of sulphur on the formation of inclusions are presented.—R. A. R.

Production of Low-Sulphur Steel to Minimize Hot Tears. G. L. McMillin. (American Institute of Mining and Metallurgical Engineers, Proceedings of the 31st National Open Hearth Conference, Apr., 1948, pp. 120–125). The relationship between sulphur content and hot tears in steel castings is discussed and methods of keeping down the sulphur are reviewed. Recommendations are: (1) Keep a high CaO/SiO_2 ratio; (2) obtain high residual manganese by adding spiegel after the charge is molten; (3) hold FeO on the low side consistent with proper working of the heat; (4) add fluorspar to maintain a fluid and active slag; and (5) use charge materials and fuel with the lowest possible sulphur content. R. A. R.

Sulphur Removal in the Basic Open-Hearth Furnace. J. A. Warchol. (American Institute of Mining and Metallurgical Engineers, Proceedings of the 31st National Open Hearth Conference, Apr., 1948, pp. 127–134). Factors affecting the rate of removing sulphur from steel in 90-ton and 125-ton open-hearth furnaces were investigated. The factors contributing most to the removal of sulphur are high basicity of the slag and good bath reaction. Factors having a negligible effect are total iron oxide in the slag, percentage of sulphur in metal, percentage of sulphur in slag, residual manganese in the metal, manganous oxide in the slag, ratio of weight of sulphur in metal to that in slag, weight of slag, and ratio of weights of metal and slag.—R. A. R.

FOUNDRY PRACTICE

Production of a Cast Iron with Good Machining Properties. G. Joly. (Fonderie, 1948, Nov., pp. 1389–1391). It was desired to produce an easily machinable cast iron with a Brinell hardness not exceeding 228. Details are given of experiments with the make-up of the charge and the operation of the cupola. The average analysis which gave the desired hardness was 3·38% carbon, 2·36% silicon, 0·62% manganese, 0·08% sulphur, and 1·03% phosphorus.—J. C. R.

Better Patching Improves Cupola Operation. T. Barlow and E. W. Claar. (Foundry, 1949, vol. 77, Mar., pp. 68–69, 254, 256, 258, 260). The authors stress the importance of good patching practice for cupolas and consider various factors that help to improve the results obtained.—J. C. R.

High-Strength Cast Irons. T. C. Jarrett. (American Society for Metals, Jan. 13, 1949: Foundry, 1949, vol. 77, Apr., pp. 66–73, 228, 230). The structure and heat-treatment of high-strength cast irons are discussed in relation

to their mechanical properties. The production of high-tensile cast-iron piston rings is described.—J. C. R.

Describes Development of Ductile Cast Iron. D. J. Reese and A. P. Gagnebin. (New Jersey Foundrymen's Association, Feb. 21, 1949: Foundry, 1949, vol. 77, Apr., pp. 111, 114, 116). An account is given of the properties of ductile cast iron, which has a graphite structure in the form of spheroids, free from graphite in the flake form. Production can be applied to common cast-iron compositions, and is based on the introduction into the iron of a small but effective amount of magnesium-containing agent such as nickel and magnesium alloy. The mechanical properties of the material in the as-cast condition and after heat-treatment are given. It has a tendency towards piping and inadequately fed sections may collapse inwardly instead of forming porous internal shrinkages. This characteristic facilitates the inspection of castings.—J. C. R.

Malleable Iron Foundry Brought Up to Date. (Foundry, 1949, vol. 77, Mar., pp. 76–79, 198). An illustrated description is presented of the Indianapolis plant of the National Malleable and Steel Castings Co., which has been modernized and re-designed to incorporate the most efficient use of mechanized equipment for the production of malleable iron castings.—J. C. R.

Mechanizes Malleable Iron Foundry. P. Dwyer. (Foundry, 1948, vol. 76, Dec., pp. 74–77, 190, 192, 194, 196, 198). An illustrated description is given of the plant of the Moline Malleable Iron Co., which has a monthly production of 425 tons of malleable iron castings and whose principal product is industrial chain links.—J. C. R.

Effect of Final Deoxidation on Low-Temperature Impact Strength of Cast Steels. B. A. Lawson. (Foundry, 1949, vol. 77, Apr., pp. 74–77, 179–180). The experimental procedure described was used to develop a deoxidation practice which would produce steel castings possessing both good ductility and low temperature impact strength. Aluminium was tried as a complete and partial substitute for ferro-carbon-titanium and also in conjunction with calcium-manganese-silicon (Ca 18%, Mn 15%, Si 55·5%). In the latter case impact strength and ductility were satisfactory, but fluidity of the metal was adversely affected. Data derived from tests with these and other combinations are presented. Acid open-hearth steel was used and the additions were made in the ladle. Both for 0·4–0·5% and 0·2–0·3% carbon steels a combination of 4 lb./ton of calcium-manganese-silicon and 4 lb./ton of ferro-carbon-titanium provided satisfactory results.—J. C. R.

Sulphur Elimination in Casting Steel. C. B. Jenni. (American Institute of Mining and Metallurgical Engineers. Proceedings of the 31st National Open Hearth Conference, Apr., 1948, pp. 125–126). Recommendations are made on methods of keeping the sulphur in cast steel below 0·030%. Foundry returns for smelting should not have sand adhering to them as this lowers the CaO/SiO_2 ratio of the slag.

R. A. R.

Effect of Cellulose Materials on Foundry Sands. T. Barlow and C. P. Loucks. (Foundry, 1949, vol. 77, Apr., pp. 82–84, 243–245). Tests were carried out on synthetic foundry sands containing separately seven cellulose materials such as wood flour. Data obtained are tabulated, and the following were amongst the conclusions reached: In moulding sands all cellulose additions decreased permeability and most of them increased deformation. Wood flour increased green compression strength, but other additions had little effect. All additions decreased the hot strength at 1000° F. and most of them that at 2000° F. All additions increased expansion at 1500° F. and increased the amount of gas produced in the mould by from 37% to as much as 105%. In oil sand cores all cellulose materials showed a minor increase in green compression strength, a drastic reduction in tensile strength; they decreased core hardness and sharply increased the collapsibility at 1500° F.—J. C. R.

Bentonite and Clay in the Foundry. P. Rossignoli. (Metallurgia Italiana, 1949, vol. 41, Jan.-Feb., pp. 19–22). The author concludes, after examining the properties of various bentonites, that there is no relation between the power of the bentonite to form a gel and the cohesion of the synthetic earth produced.—R. F. F.

Australian Bentonite. C. Lynch. (Chimie et Industrie, 1949, vol. 61, Feb., p. 189). The deposits and uses of Australian bentonite are described.—R. F. F.

Moulding Techniques and Methods with Special Reference to the Cement-Sand Moulding Shop. K. Ingendahl. (Neue Giesserei, 1949, vol. 36, Mar., pp. 74–78). Improvements in methods of moulding are reviewed and the Schiess cement-sand process is described in which the facing sand is a cement-sand mixture and the backing consists of quartz, crushed ballast, or granulated metal without a binder. Examples of moulds and castings made by this method are described and illustrated.—R. A. R.

HEATING FURNACES AND SOAKING PITS

Modern *vs.* Old-type Soaking Pits for Steel Ingots. F. N. Hays. (American Institute of Mining and Metallurgical Engineers, Proceedings of the 31st National Open Hearth Conference, Apr., 1948, pp. 255–265). The advantages and disadvantages of several designs of soaking pits are discussed.—R. A. R.

Some Experiences with Soaking Pits. H. V. Flagg. (Yearly Proceedings of the Association of Iron and Steel Engineers, 1948, pp. 739–746). *See* Journ. I. and S.I., 1949, vol. 161; Apr., p. 377.

Continuous Induction Heating Set-Up Expedites Rock-Bit Forging. W. J. Assel. (Steel, 1949, vol. 124, Mar. 28, pp. 66–67). In the manufacture of rock-drilling bits from round bar at Timken Roller Bearing Co., Wooster, O., a continuous process is used in which the bar stock is heated by electromagnetic induction in two stages, first to 1500° F. (805° C.) and then to 2150° F. (1176° C.), as it is pushed intermittently by pneumatic means through the coils. As forging temperature is reached, slugs are cut off and upset. Considerable savings of power, and 2% of total steel weight, are claimed over older methods of shearing into slugs before heating.—J. P. S.

HEAT-TREATMENT AND HEAT-TREATMENT FURNACES

Isothermal Hardening of Steels. D. Séférian. (Bulletin Technique Japy, 1948, No. 1, June, pp. 6–7, 16; No. 2, Sept., pp. 5–7. [Abstract] Centre de Documentation Sidérurgique, Bulletin Analytique, 1948, vol. 5, Nov., p. 31; Dec., p. 33). The author discusses the mechanism of hardening, the isothermal decomposition of austenite, the advantages of isothermal hardening, the mechanical properties of isothermally hardened steels, factors connected with this method of hardening, and the application of the method to a 2% chromium steel.

Isothermal Heat Treating. F. R. Morral. (Wire and Wire Products, 1949, vol. 24, Jan., pp. 39–47; Feb., pp. 152–159; Mar., pp. 236–243). This article assembles data from the literature to facilitate the rapid construction of **S**-curves for the heat-treatment of over 400 steels. The first table presents the analyses of the steels and indicates the type of curve to which each steel may be assigned. Another table gives data on the details of heat-treatment, grain size, quenching media and hardness. There are 79 references to the literature.—R. A. R.

Isothermal Hardening. Seidler and Tauscher. (Die Technik, 1949, vol. 4, Mar., pp. 103–105). The results are presented of hardness, tensile, and impact tests on specimens of seven steels (including unalloyed high carbon steel, low alloy chromium and chromium–nickel steels, and a 1·26% manganese steel) after ordinary hardening and tempering, and after isothermal hardening in salt baths (at 200° and 300° C.). Isothermal hardening is recommended for 0·9% carbon, 0·7% manganese steel, and 1·2% carbon, 0·4% manganese steel for thicknesses up to 10 mm. and 15 mm. respectively.—R. A. R.

Heat Treatment of Steel. G. H. Jackson. (British Engineering, 1949, vol. 31, Mar., pp. 1468–1476). This review describes the processes of austempering, martempering, sub-critical annealing, combining isothermal and sub-zero treatments, gas-carburizing, high-frequency brazing, and high-frequency hardening.—R. A. R.

Martempering. R. H. Aborn. (Metal Progress, 1949, vol. 55, Jan., pp. 65–73). The author presents data on martempered carbon and low-alloy steels, and gives specific information about distortion, cracking, and the maximum size of bar that can be hardened by martempering. The advantages of the process are: (1) Steel is less likely to crack (2) distortion is minimized; (3) improved control of inevitable

dimensional changes; and (4) some self-tempering occurs during air cooling so that the steel may be suitable for some applications without further tempering. The limitations of the process are: (1) Composition; for a given section size, the minimum carbon or alloy content must be somewhat higher than in conventional quenching for the same percentage of martensite; (2) section size; for a given composition the section size that can be made fully martensitic (or treated to any lower hardness) is somewhat less than for efficient quenching in oil or water; (3) less decarburization and scale are allowable in martempering; (4) more elaborate heat-treating equipment is required; (5) more time, space and equipment are needed to handle the same volume of work; (6) there are greater safety hazards in working with molten baths; and (7) the salt film must be removed from the hardened product.—J. C. R.

Structural Changes during Continuous Cooling. C. A. Liedholm. (Metal Progress, 1948, vol. 54, Dec., pp. 849–856). The author indicates how information shown on continuous cooling diagrams and data obtained from flat Jominy bars can be advantageously used in planning practical heat-treatments.—J. C. R.

Furnace Atmospheres—Their Generation and Use. W. F. Barstow. (Metal Treating Institute: Steel Processing, 1949, vol. 35, Feb., pp. 91–97). Fundamental theory relating to the heat-treatment-furnace gas reactions is discussed, and the following types of furnace atmosphere generators are described: (1) Exothermic generators in which a gaseous fuel is burnt with insufficient air; (2) exothermic nitrogen generators; (3) endothermic gaseous fuel cracking units; (4) ammonia dissociators; and (5) charcoal generators.

R. A. R.

Some Industrial Uses of Nitrogen and the Rare Gases. J. M. Crockett. (Metal Progress, 1948, vol. 54, Dec., pp. 833–836). The use of nitrogen, helium and argon for flushing hydrogen from liquid metals and for protective atmospheres in heat-treating is discussed. Reference is also made to their application in inert-gas-shielded arc welding.—J. C. R.

Protective Atmospheres in Industry. A. G. Hotchkiss and H. M. Webber. (General Electrical Review, 1948, vol. 51, Nov., pp. 29–35; Dec., pp. 41–48: [Abstract] Bulletin of the British Non-Ferrous Metals Research Association, 1949, Mar., p. 117). The first part describes advantages and applications and gives compositions and costs of typical protective atmospheres. The second part considers theory of chemical reactions occurring in the principal types of gases commonly used.

Controlled Atmospheres for Annealing Gas. C. E. Peck. (Iron and Steel Engineer, 1949, vol. 26, Feb., pp. 73–87). The author discusses various types of atmospheres which are applied to the annealing of steels and in relation to each gives its chemical composition, a description of equipment used to produce it, its cost of production, particular phases of chemical effects, importance of water vapour and its control, control of composition, specific applications to certain types of furnace, atmosphere flow and distribution and consumption, as well as practical views on operation and maintenance. Particular reference is made to high-nitrogen-bearing atmospheres and the possibility of using them in the annealing of steel.—J. C. R.

Five Zone Rotary Furnace. (Steel, 1949, vol. 124, Mar. 28, pp. 88, 91–96). The construction of a large new rotary-hearth furnace at the seamless tube plant of the National Tube Co., Gary, Indiana, is described. Its capacity is 50 tons/hr. of billets 8 in. in dia. by 16 ft. long, heated from room temperature to 2350° F. (1290° C.). It can be fired with coke-oven gas, natural gas, or fuel oil. Each of the five zones may be controlled for temperature and pressure independently and has its own individual stack.—J. P. S.

Heat Treatment Lowers Manufacturing Costs. R. W. Campbell. (Steel Processing, 1949, vol. 35, Feb., pp. 71–74). Several examples are cited of applications of heat-treatment which have resulted in reduced costs of production or longer life to the part.—R. A. R.

Walking Beam Furnace Keeps Spring Leaves Aligned as They Are Heated. (Industrial Heating, 1948, vol. 15, Dec., pp. 2112–2114). A brief description is given of a walking-beam furnace built by the Bellevue Industrial Furnace Co., Detroit, for the heat-treatment of leaf springs. The beams are fitted with fingers which prevent the leaves from working over to one side of the furnace and jamming the flow.

FORGING, STAMPING, DRAWING, AND PRESSING

German Power Press Industry. (British Intelligence Objectives Sub-Committee, 1949, Report No. 1826: H.M. Stationery Office). This report covers both the technical and commercial aspects of the German power-press industry, the information presented having been obtained by visits to manufacturers of presses, press tools, and works where motor-car bodies, cutlery, drums and cans, electrical fittings, general pressings, and hot stampings were made. Developments in German power-press design since 1939 have been negligible, but the industry is of great commercial importance.—R. A. R.

The Use of Hard Metals for Blanking Tools. R. Champeval. (Microtecnic, 1949, vol. 3, Jan.–Feb., pp. 34–37). Some advantages of using hard-metal blanking dies are enumerated and an example is cited of its advantageous use for making small levers for watches.—R. A. R.

The Production of Nuts by the New Cold-Pressing Process. (Österreichischer Maschinenmarkt und Elektrowirtschaft, 1949, vol. 4, Feb. 15, pp. 47–48). The new cold-pressing process for making hexagon nuts, developed by F. B. Hatebur, Basle, is described and illustrated.—R. A. R.

Science and Practice in Bar Drawing. F. Boehm. (Stahl und Eisen, 1949, vol. 69, Feb. 17, pp. 105–117). The theory of the flow of metal when drawing bars through dies is explained. The total energy consumption is analysed to show the proportions consumed in the work of deformation, internal displacement, friction, and mechanical losses of the power unit and in power transmission. Handy formulæ for use in the drawing shop are reviewed. Die angle and degree of reduction, which are the most important factors affecting material flow, control the properties of the product, and their adjustment to produce the most economic conditions of drawing is discussed.—R. A. R.

Carbide Die Construction. (Steel Processing, 1949, vol. 35, Jan., pp. 21–23). The design, diamond boring, grinding, and lapping of carbide dies for drawing rings 4 in. inside dia. $\times$ $\frac{1}{16}$ in. thick are described.—R. A. R.

The Production of Cold-Drawn Wire of Triangular Cross-Section. S. I. Masalov. (Iron and Steel Institute, Translation Series, 1949, No. 377). This is an English translation of a paper which appeared in Kachestvennaya Stal, 1938, No. 2, pp. 45–46. (*See* Journ. I. and S.I., 1939, No. II, p. 153A).—R. A. R.

Electric Equipment for Wire Winders. J. G. Roby and H. R. Lloyd. (Wire and Wire Products, 1949, vol. 24, Mar., pp. 231–234; Apr., pp. 320–327, 363–365). Winding operations in wire mills are analysed and recommendations are made on the power requirements and the most suitable size of motor for the various processes.—R. A. R.

ROLLING-MILL PRACTICE

Hot Mill Drives. (Iron and Steel, 1949, vol. 22, Mar., p. 76). A brief description is given of a double reduction transmission unit, installed at the Wolverhampton works of Joseph Sankey and Sons, for driving a finishing and two breaking-down mills on the same train. It comprises a 40-in. $\times$ 70 in. centres double-reduction helical gear unit for a duty of 750-h.p. normal, 5000-h.p. frequent peak, and 8000-h.p. maximum emergency peak at 720/30 r.p.m. with flywheels on the high-speed shaft having a total stored energy of 15,000 h.p. seconds.—J. C. R.

Electrical Developments in the Steel Industry—1948. H. W. Poole. (Blast Furnace and Steel Plant, 1949, vol. 37, Jan., pp. 77–80). Developments on the electrical engineering side of the steel industry have included the use of twin motor drives on rolling mills, the use of large mercury-arc rectifiers as direct current suppliers to the finishing train of a hot-strip mill, the use of alternators to supply 9600-cycle power for induction heating, and the practical application of the X-ray thickness gauge for continuous hot-strip measurement. The extension of the magnetic amplifier to use in regulating circuits usually requiring an amplidyne or electronic amplifier is foreseen.—J. P. S.

Advances in Steel Mill Electrification in 1948. W. R. Harris. (Blast Furnace and Steel Plant, 1949, vol. 37, Jan., pp. 85–90). Typical electrical installations for blooming mills, rod mills, hot strip mills, tandem cold reduction mills, reversible cold mills and temper pass mills, processing lines

such as pickling or tinning, and arc furnaces are described. In all these applications the aim has been to obtain higher productive speeds, more rigid quality control and more automatic operation.—J. P. S.

Current and Voltage Choice for Stationary Drives and Cranes in the Metal Industry. S. M. Livshits. (Vestnik Electropromyshlennosti, 1948, No. 5, pp. 1–7: Electrical Engineering Abstracts, 1949, vol. 52, Feb., p. 65). Prevailing types of electric drives for rolling mills and other metallurgical plants are surveyed and compared from the operational and economic standpoints. Strong recommendations are made for general use of 3-phase 350-V. supplies; D.C. should be restricted to cases needing wide speed regulation. Cranes should be exclusively 3-phase operated; synchronous motors should be used for elevators.

Manufacture of Mill Type Motors. C. B. Hathaway. (Yearly Proceedings of the Association of Iron and Steel Engineers, 1948, pp. 235–236). *See* Journ. I. and S.I., 1948, vol. 159, June, p. 219.

Twin-Motor Drives for Cold Mills. R. H. Wright. (Yearly Proceedings of the Association of Iron and Steel Engineers, 1948, pp. 703–711). *See* Journ. I. and S.I., 1949, vol. 161, Mar., p. 261.

Large Electronic Direct Current Motor Drives. M. M. Morack. (Yearly Proceedings of the Association of Iron and Steel Engineers, 1948, pp. 424–429). *See* Journ. I. and S.I., 1948, vol. 160, Oct., p. 226.

Power for an Industrial Plant—Steam. E. M. Yard. (Yearly Proceedings of the Association of Iron and Steel Engineers, 1948, pp. 875–877). *See* Journ. I. and S.I., 1949, vol. 162, May, p. 116.

Power for an Industrial Plant—Electric Power. W. E. Zelley. (Yearly Proceedings of the Association of Iron and Steel Engineers, 1948, pp. 878–884). *See* Journ. I. and S.I., 1949, vol. 162, May, p. 116.

Improved D.C. Generators for Reversing Mills. C. Lynn and W. H. Burr. (Yearly Proceedings of the Association of Iron and Steel Engineers, 1948, pp. 113–123, 138). *See* Journ. I. and S.I., 1948, vol. 159, June, p. 219.

Mild Steel Rolling-Mill Bearings. (Verein deutscher Eisenhüttenleute, 1943, Confidential Report No. 48). Bronze bearings in a Silesian 830-mm. three-high mill and subsequently in hot sheet mills were replaced by very soft steel. Suitable steel should contain less than 0·03% of carbon, with 0·07–0·04% of manganese. The bearings were forged under a drop stamp and ground. The operational results were very satisfactory.—G. W. A.

Synthetic Phenol-Base Resins and Their Application in Rolling Mills. W. Nowakowski. (Hutnik, 1948, vol. 15, Sept., pp. 379–386). [In Polish]. The chemical considerations in the production of synthetic phenol-base resins, are given and the application of these plastic materials in rolling mill bearings are discussed.—W. J. W.

Design, Construction and Lubrication of Mill Couplings and Spindles. W. L. Stover. (Yearly Proceedings of the Association of Iron and Steel Engineers, 1948, pp. 472–478). *See* Journ. I. and S.I., 1948, vol. 160, Oct., p. 226.

Application of the Basic Principles of Rolling in Roll Design. R. E. Beynon. (Yearly Proceedings of the Association of Iron and Steel Engineers, 1948, pp. 381–403). *See* Journ. I. and S.I., 1948, vol. 160, Oct., p. 226.

The Art of Rolling Hexagons and Octagons. C. P. Hammond. (Yearly Proceedings of the Association of Iron and Steel Engineers, 1948, pp. 555–568). *See* Journ. I. and S.I., 1949, vol. 161, Feb., p. 155.

The Art of Roll Pass Design. R. E. Beynon. (Steel, 1949, vol. 124, Apr. 4, pp. 112, 113, 117–124). A general consideration of the factors involved in the design, casting, and turning of rolls is given; illustrations depict the roll passes for bars, flats, channels, angles, **Z** sections, beams, pile sections, etc.

Rolls and Rolling. E. E. Brayshaw. (Blast Furnace and Steel Plant, 1949, vol. 37, Jan., pp. 81–84; Feb., pp. 206–211; Mar., pp. 325–334) In the first article, the general considerations involved in change of dimensions by rolling are outlined and the most common types of roll pass are described and depicted. Next is considered the design of blooming-mill passes and the importance of their correct location along the roll; a compromise is often necessary between the requirements of smooth working and the necessity to maintain the strength of the roll by having the deeper passes at the ends only. The roll design for various types of blooming-mill is then considered, including three-high blooming-mills, continuous blooming-mills and mills for specialized shapes such as beam-blanks.—J. P. S.

Technical Developments in the Manufacture of Full Finish Steel Sheets. W. H. R. Bird. (Sheet and Strip Metal Users' Technical Association: Sheet Metal Industries, 1949, vol. 26, Mar., pp. 513–524). The development of autobody steel sheet is discussed under the headings of improving the sheet surface, and improving the drawability. The relationship between surface quality and steelmaking technique, and rolling and processing is dealt with. As to chemical segregation, if the carbon in the steel is kept below about 0·06%, no segregation of carbon can take place during solidification. To prevent recrystallization in a high-sulphur area of the core it is necessary to start with a casting-pit sulphur content of < 0·025%. Non-ageing or stabilized steel can be produced by killing in the ladle with at least 4 lb. of aluminium per ton of steel. A test for non-ageing steels is described in which the test-piece is strained 5%, removed from the machine and artificially aged by placing in boiling water for 2 hr. A second tensile test is made and the two curves are compared; the degree of ageing, or index value, is the percentage increase of load after straining and ageing compared with the load after straining only.—R. A. R.

Automatic Control of Tension, Speed, and Position in Handling Metal Strip. J. H. Hopper. (Blast Furnace and Steel Plant, 1949, vol. 37, Mar., pp. 317–322, 386–388). The author describes the use of amplidynes and of tensiometers in controlling strip tension in processing lines, of amplidynes and "Thy-mo-trol" gear in speed regulation. For the control of free-hanging loops, which may be necessary for strip storage, for the provision of zero tension, for lateral guidance, or for acid pickling or heat-treatment, a 'dancer' roll in the loop may be positioned between a light source and a photoelectric cell, affecting the output of the latter by its movement. Photoelectric means may also be used to provide side register so that coils may be evenly bound on the reel, and to provide accurate centring of strip entering side trimmers.—J. P. S.

Columbia Steel's New Sheet and Tin Mill. P. F. Kohlhaas. (Yearly Proceedings of the Association of Iron and Steel Engineers, 1948, pp. 722–738). *See* Journ. I. and S.I., 1949, vol. 161, Apr., p. 380.

New Facilities at Gary Sheet and Tin Mill Offer Increased Tin-Plate Capacity. (Steel, 1949, vol. 124, Mar. 28, pp. 86, 103, 106, 108). New equipment at Carnegie-Illinois Steel Corporation's Gary Sheet and Tin Mill includes a new 54-in. four-stand cold reduction mill, a 60-in. high-speed temper mill, 54-in. electrolytic-cleaning, side-trimming, and slitting and shear lines; a new galvanizing and a new terne coating line have also been installed. Changes on the 80-in. continuous hot mill have included improvements to the slab heating furnaces, handling equipment, and coilers.—J. P. S.

WELDING AND FLAME-CUTTING

Butt Welding Methods Employed in Pipe Erection and Fabrication in Germany. (British Intelligence Objectives Sub-Committee, 1949, Report No. 1848: H.M. Stationery Office). Short reports on visits to nine German companies engaged in pipe erection and fabrication by various forms of welding are presented. All of them had developed their technique of welding, whether by oxy-acetylene, atomic hydrogen electric arc, or purely electric arc, by trial and error.—R. A. R.

Republic Steel's Gadsden Pipe Mill Now Operating at Full Capacity. C. Longenecker. (Blast Furnace and Steel Plant, 1949, vol. 37, Feb., pp. 220–222). The manufacture of welded pipe of 24-in. outside diameter from plate is described; submerged-arc welding is used for both inside and outside seams. The welded pipe is subjected to cold working by hydraulic expansion at 1500–2000 lb./sq. in. which expands the pipe and also detects leaks or other flaws.—J. P. S.

Developments in Continuous Butt Weld Pipe Mills. W. Rodder. (Iron and Steel Engineer, 1949, vol. 26, Feb., pp. 101–111). A detailed description is given of the units which comprise a modern butt weld (Fretz-Moon) pipe mill. J. C. R.

Riveted *vs.* Welded Ship Structures. E. M. MacCutcheon. (Welding Journal, 1949, vol. 28, Feb., pp. 111–117). Little

valid evidence exists as to the relative susceptibilities to cracking of riveted and welded ship structures. It is agreed that both types of structure are liable to crack, with similar types of fracture, and that riveted joints may slip in service at moderate loadings (above 6000 lb./sq. in. shear stress), and cause an increase of stress at critical portions of the structure.—J. P. S.

Fabrication of Structural Steel Sections. J. M. Tippett. (Welding Journal, 1949, vol. 38, Feb., pp. 123–127). The use of automatic submerged arc welding for fabricating I-beams from plate and angles, box-sections from channels and angles, and for welding tubes and more complex components is described.—J. P. S.

The Present Position in the Problem of the Weldability of Structural Steels. M. Lefèvre. (Arcos, 1947, Oct., 1948, Jan.: [Abstract] Revue Universelle des Mines, 1949, Series 9, vol. 5, Mar., p. 104).

Submerged Melt Welding in Steel Mills. E. D. Morris. (Yearly Proceedings of the Association of Iron and Steel Engineers, 1948, pp. 885–888). *See* Journ. I. and S.I., 1949, vol. 162, May, p. 118.

Submerged Arc Welding for Maintenance. C. C. Keyser. (Yearly Proceedings of the Association of Iron and Steel Engineers, 1948, pp. 639–644). *See* Journ I. and S.I., 1949, vol. 161, Mar., p. 263.

Welding of Stainless Steel by Atomic Hydrogen. M. Beauvais. (Machines Modernes, 1948, vol. 42, Jan., pp. 9–10).

The Welding of Stainless Steel. N. C. Jelley. (New Zealand Engineering, 1948, vol. 3, Dec. 10, pp. 1188–1189). Recommendations on techniques for oxy-acetylene and electric welding stainless steel are made.—R. A. R.

The Powder Process in Stainless Steel Production. C. J. Burch and E. M. Holub. (Yearly Proceedings of the Association of Iron and Steel Engineers, 1948, pp. 453–462). The cutting of stainless steel with the oxy-acetylene flame into which a stream of fluxing powder is directed is described. *See* Journ. I. and S.I., 1948, vol. 160, Nov., p. 327.

Hard Surfacing of Cast-Steel Propeller Blades. K. B. Young, H. J. Nichols, and M. J. Nolan. (Welding Journal, 1949, vol. 28, Feb., pp. 153–157). The effect of cavitation and salt-water corrosion on hard-surfaced cast steel ships' propeller blades has been examined. Galvanic corrosion of the uncoated steel was noted, as well as some sub-surface effects due to the deposition of one layer on another. The use of a lead wipe coating with a tin–lead–antimony composition gave some protection to uncoated blades. The service life of hard-surfaced blades is considered to be equal to that of manganese–bronze blades.—J. P. S.

Welding Alloy Steels for High Temperature Service. M. E. Holmberg. (Welding Journal, 1949, vol. 38, Feb., pp. 141–148). High temperature oil and gas processing impose special conditions upon the alloys used, especially where there is a risk of the cracking of hydrocarbons and the deposition of carbon; other harmful conditions, such as the condensation of corrosive fluids, and repeated heating and cooling, may also be imposed. Practice to be recommended depends on conditions, but hydrocarbon cracking may be avoided by proper design of parts, and where thermal cycles occur, the thermal conductivity and expansion of the materials as well as the connections between materials of different sections must be taken into account. The use of austenitic rods for welding ferritic materials such as chromium–molybdenum steels, except when the components are exposed to cyclic temperature changes, is approved.—J. P. S.

MACHINING AND MACHINABILITY

The Machining of Stainless Steel. L. F. Spencer. (Steel Processing, 1949, vol. 35, Jan., pp. 31–35, 51; Feb., pp. 82–85, 98). The nature of stainless steel and the reasons for its poor machinability are pointed out. High-speed, cast alloy, and cemented carbide tools for machining it and suitable cutting fluids are described in Part I, whilst cutting speeds and feeds are given in Part II which also quotes the results of tests by S. P. Watkins on the corrosion of free-machining stainless steel in HNO_3, HCl, and $C_2H_4O_2$.—R. A. R.

The Roller-Turning of Bars. R. Hartl. (Österreichischer Maschinenmarkt und Elektrowirtschaft, 1949, vol. 4, Mar. 15, pp. 67–68). A description is given of two machine tools, one for roller-turning, and the other for straightening and polishing bars. The first consists of a hollow cutting head carrying the cutting tool and rollers which rotate round the bar; the bar does not rotate, but is moved forward through the head by feed rollers. For the second process the bar also passes through a hollow head which carries the straightening and polishing rolls.—R. A. R.

Reproducibility of Tungsten Carbide in the Milling of Cast Iron. K. G. Lewis. (Iron and Coal Trades Review, 1949, vol. 158, Mar. 18, pp. 563–570). An account is given of an investigation on the possibilities of the negative-rake milling of cast iron, and the mechanism underlying negative-rake machining is discussed. Test conditions are described, and the usefulness of flycutting as a basis of test is outlined. Feed-life curves are given and evidence is submitted of an optimum speed value. The performance of an unsuitable carbide is given, and modes of tool failure and the metallurgical aspects of carbide performance are discussed.—J.C.R.

"Cool" Grinding Surface Hardened Steel. H. J. Chamberland. (Steel, 1949, vol. 124, Jan. 31, pp. 56–58). Temperatures of 1500° F. to 2200° F. (820° C. to 1200° C.) may be generated during grinding: unless this heat is absorbed by the coolant, distortion or cracking will result. A new coolant consisting of colloidal graphite suspended in a high grade oil has been developed: it readily emulsifies with water, and the emulsion has excellent wetting properties. A new "cool grinding" system has also been developed whereby the coolant is fed through a special wheel adaptor on to the sides of the grinding wheel near the arbor and finds its way, through the porosity of the wheel, to the point of grinding.—J. P. S.

New Diamond Wheel Recommendations for Carbide Grinding. F. J. Benn. (Grits and Grinds, 1948, vol. 39, No. 8, pp. 1–5: American Ceramic Abstracts, 1949, vol. 32, Jan. 1, p. 1). Maintenance and production costs can be lowered through reduced wheel expenditures and grinding time when grinding sintered carbides. Advice is given for the selection of the bond, whether resinoid, vitrified, or metal. Correct selection of grit size is very important. Diamond wheels in each of the three bond types tend to be harder as the grit size becomes coarser, and therefore a grit size corresponding to the desired finish should be used. The importance of grade or hardess and diamond concentration of the three bonds, and the best method of truing and treating the wheels during operation are discussed. A table of wheel recommendations is given.

The Production of Exact Geometrical Forms by Electrolytic Polishing. P. Michel. (Société Française de Métallurgie, Oct. 10, 1947: Revue de Métallurgie, Mémoires, 1949, vol. 46, Jan., pp. 39–44). The author's aim was to use electrolytic polishing as a method of superfinishing. After summarizing the factors causing irregularities in electrolytic polishing and their consequences, he describes the various means that he used in trying to obtain a simple cylinder and a gudgeon pin, polished to the exact dimensions desired: Various arrangements of the anode (use of conducting sleeves, non-conducting screens, counter-electrodes) and of the cathodes (concentric and eccentric about the anode). The author finally succeeded in polishing electrolytically the pieces to the exact dimensions required, but concludes that as a method of superfinishing the process is of only limited application. The modification of the physical and mechanical properties of the surface due to the process is also discussed.—A. E. C.

POWDER METALLURGY

Alloy Steels—Production by Powder Metallurgy. H. W. Greenwood. (Iron and Steel, 1949, vol. 22, Jan., pp. 9–10). The author discusses the production of small parts in alloy steels using powders, where machining or precision casting would be uneconomical. Details are given of experimental work on the production of nickel steel from powders, and it is emphasized that a notable advantage possessed by components produced by this process is that they can be hardened by cyanide or pack-carburizing.

Sintered Hard Metals as Wear-Resisting Materials. R. Kieffer and F. Benesovsky. (Verein der Ingenieure in Tirol: Industrie und Technik, 1948, vol. 3, No. 12, pp. 251–257). This paper reviews the literature on factors affecting wear, the hardness and strength of sintered carbides, effects of additions of other carbides to tungsten carbide, methods of determining the hardness of sintered carbides, and applications of the sintered carbides.—R. A. R.

PROPERTIES AND TESTS

What are the Fundamental Properties Essential for the Characterisation of the Mechanical Properties of Materials. C. Benedicks. (Société Française de Métallurgie, Oct. 20, 1948 : Revue de Métallurgie, Mémoires, 1949, vol. 46, Jan. pp. 1–6). The upper yield-point is not a property characteristic of a homogeneous substance ; it presupposes the existence of heterogeneity caused by adsorption at the grain boundaries. The parameters of two points in tension and two in compression are all that need be known, and, as the values differ for tension and compression only in sign, only four parameters are in fact required : (*a*) The elastic limit and the corresponding elongation ; (*b*) the breaking stress and the elongation at rupture.—A. E. C.

The Micromechanical Testing of Metals. P. Chevenard. (Schweizer Verband für die Materialprüfungen der Technik, 1947, Apr., Report No. 42, pp. 3–36 : [Abstract] Applied Mechanics Review, 1948, vol. 1, Aug., p. 218). The article consists of two parts, the first dealing with the construction of various apparatus used for micromechanical testing of materials, the second giving a number of applications. The author gives an explanation of the choice of test-bar dimensions (dia. 1·5 mm. and length 7·5 to 10 mm.). The following microtesting machines mostly commercially available, are described : (1) For tension, shear, and bending ; (2) for tension of fine wires, textile fibres, etc. ; (3) for continuous torsion ; (4) for alternating torsion ; (5) for the measurement of creep at high temperatures ; and (6) for impact tests. The necessary amplifications of the deformation and the magnitude of the force are obtained optically, and the displacements of the light-spot are registered on a photographic plate. It is claimed that the accuracy is very good. The subjects in the second part have the following headings : (1) Real mechanical properties of materials. Deviations from Hooke's law. (2) Plasticity of metal crystals and microcrystalline yielding. (3) Crystalline anisotropy of metals due to deformation at low temperature. Choice of the Poisson ratio as a proof of anisotropy. (4) Micromechanical study of a heterogeneous piece of material. (5) Mechanical hysteresis and fatigue. In each part valuable remarks are made, and the results are presented in the form of a great number of graphs and pictures.

On the Behaviour of the Elastic Moduli of Ordered Alloys near the Curie Point. L. Kholodenko. (Journal of Experimental and Theoretical Physics, U.S.S.R., 1948, vol. 18, Sept., pp. 812–817 : Physics Abstracts, 1949, vol. 52, Feb., p. 88). The behaviour of the elastic moduli near the Curie point is considered on the basis of Landau's theory of second-order phase transitions. The discontinuities of the elastic moduli are shown to be very small. A relation between the discontinuities of the temperature gradients of the elastic moduli and the discontinuities of the temperature gradients of the coefficients of thermal deformation and heat capacity was derived. This formula is considered in its application to β-brass.

The Isotropic Law of Elasticity. H. Richter. (Zeitschrift für angewandte Mathematik und Mechanik, 1948, vol. 28, July–Aug., pp. 205–209 : Physics Abstracts, 1949, vol. 52, Feb., p. 88). The conditions of isotropy and of the existence of thermodynamic potentials lead to a general form of the three-dimensional law of elasticity. This is obtained from the logarithmic strain matrix permitting a separation of the change of volume from the deformation by forming the ordinary deviation. The elastic energy represents the exact sum of energy of volume change, and of deformation only if the mean stress is a function of the change of volume alone. For finite deformations Hooke's law applies only when the Poisson's ratio = 3.

Tests on the Volume Expansion of Steel under Tensile Stresses Causing Elastic-Plastic Deformation. Casse. (Travaux, 1948, vol. 32, May, pp. 279–281 : [Abstract] Centre National de la Recherche Scientifique, Bulletin Analytique, 1948, vol. 9, No 11, p. 3177). Experiments have been made to determine the relationship of volume expansion of soft and semi-soft steel to elastic and plastic elongation. The laws of plastic deformation were only strictly applicable after considerable deformation.

On the Range of the Fractures of Tensile Specimens. A. M. Palii. (Zavodskaya Laboratoriya, 1949, vol. 15, Jan., pp. 102–104). [In Russian]. The conditions leading to various types of fracture of the specimen in tensile tests are considered and a system for the classification of such fractures is proposed.—S. K.

Low-Temperature Impact of Annealed and Sensitized 18-8. E. H. Schmidt. (Metal Progress, 1948, vol. 54, Nov., pp. 698–704). The effect of cold work on stainless steel has been investigated using a work-brittleness test in which a round tapered steel specimen is drawn through a die and then notched for impact testing. Austenitic steels of the American types 302 and 304 (0·14% and 0·07% carbon respectively) were compared in the fully annealed and in the sensitized conditions. Data derived from tests are presented and analysed, and illustrated descriptions are given of the results of microscopic examination. The following conclusions are reached : (1) Grain-coarsening through heat-treatment results in lowered notch impact values at subatmospheric temperatures ; (2) the degree of sensitization is proportional to the carbon content in the austenitic 18/8 alloys ; (3) cold deformation increases hardness ; (4) ductility, as measured by the Charpy keyhole notch impact test, decreases with increasing amounts of cold work ; (5) both types 302 and 304 stainless steels in the annealed state are only slightly temperature sensitive ; (6) type 304 stainless steel in the sensitized condition is stable, as far as energy-absorption values are concerned, down to − 150° F. ; at − 300° F. impact values dropped 20 to 30 ft.lb. ; (7) sensitized type 302 stainless steel shows increasing embrittlement with decreasing temperatures ; and (8) at − 300° F. the notch toughness of sensitized type 302 stainless steel is not affected by cold work.—J. C. R.

Relations between Disturbances in the Metallic Lattice and the Hardness due to Cold Work. W. Boas. (Société Française de Métallurgie, Oct. 18, 1948 : Revue de Métallurgie, Mémoires, 1949, vol. 46, Feb., pp. 84–88). The modifications in the lattice of a metal due to cold-working give rise to changes in the X-ray spectra, but the interpretation of these alterations is very difficult. The present article reviews present-day knowledge of the subject and indicates what may be regarded as definitely fixed concerning the relations between the modifications of the metallic lattice and the effect of hardening by cold-working.—A. E. C.

Practical Stress Analysis at I-H. J. A. Halgren, S. A. Sheridan, and B. Goodman. (Iron Age, 1949, vol. 163, Mar. 17, pp. 76–80). Some applications of stress analysis, by means of strain gauges at the works of International Harvester Co., to such parts of agricultural machinery as transmission cases, take-off housings, and connecting rods and bolts, are described.—J. P. S.

Strain Gage for Testing Sheet Metal at High Temperature. G. Guarnieri and J. Miller. (Metal Progress, 1948, vol. 54, Nov., pp. 692–694). An illustrated description is given of an extensometer and an instrument utilizing eight cantilever strain gauges, so mounted as to cancel out numerous variables and record a single equated value at any instant. Using this instrument, elastic modulus, proportional limit, yield stress, and creep deformations of sheets at temperatures up to 1800° F. can be determined. The instrument permits routine and accurate measurement of 0·00010 in. change in gauge length over a range of approximately 0·2 in. Details are given of the calibration and operation of the instrument.—J. C. R.

The Acoustic Strain Gauge. (Muirhead Technique : New Zealand Engineering, 1948, vol. 3, Dec. 10, pp. 1167–1169). The acoustic strain gauge makes use of the changes in frequency of vibration of a stretched steel wire clamped to the structure under test. Some applications of such a gauge are described.—R. A. R.

Some Notes on Brittleness in Mild Steel. J. Görrissen. (Journal of The Iron and Steel Institute, 1949, vol. 162, May, pp. 16–28). Brittle fracture in unkilled mild steel such as that used in chain manufacture was investigated with special reference to the effect of grain-size and structure. It was confirmed that grain boundary cementite is not formed above the temperature of A_1, but is formed during slow cooling from A_3 to room temperature. It is essential to anneal above A_3 to avoid a coarse-grained ferrite structure. Fast cooling lowers the transition range temperature because of the finer ferrite grain-size and more beneficial pearlite–cementite structure. Slow cooling-rates are detrimental to impact properties. Too fast cooling-rates may introduce embrittlement due to quench-ageing. Steels alloyed with 0·05% to 0·30% of silicon or 1·25% to 1·50% of manganese

are considered more suitable than mild steel for chain-making. The addition of aluminium is beneficial in controlling grain-size and reducing liability to ageing. Up to 0·25% of carbon does not affect the impact value.

Prestresses and Surface Hardening of Steel Pieces. J. Pomey. (Société Française de Métallurgie; Oct. 10, 1947: Revue de Métallurgie, Mémoires, 1949, vol. 46, Jan., pp. 46–54; Feb., pp. 108–120; Mar., pp. 163–180). *See* Journ. I. and S.I., 1948, vol. 159, July, p. 339.

Testing the Quench-Hardenability of Steel with Small Plates. H. Krainer, K. Swoboda, and F. Rapatz. (Stahl und Eisen, 1949, vol. 69, Feb. 17, pp. 122–127). A simple and rapid means of determining the hardenability of steel is described. For this purpose small plates 50 × 20 × 2 or 3 mm. are quenched in a lead bath and their hardness determined. After experience has been gained, the bath temperature and immersion time which produce a very rapid austenite → pearlite transformation can be selected so that the test is sufficiently rapid for open-hearth control purposes.—R. A. R.

Microhardness Tests. (Österreichischer Maschinenmarkt und Elektrowirtschaft, 1949, vol. 4, Jan. 31, pp. 6–10). The Zeiss-Hanemann micro-hardness tester and some of its applications are described.—R. A. R.

Research on the Properties and Characteristics of Puddled Iron. III. Mechanical Properties and Behaviour during Ageing. N. Collari and A. Pala. (Calore, 1946, vol. 17, Nov., pp. 203–207). [In Italian].

Thoughts on the Problem of Wear. W. Bottenberg. (Neue Giesserei, 1949, vol. 36, Feb., pp. 39–45). The most important methods of determining the wear resistance of iron and steel are briefly described; the results obtained by the different methods are not comparable. It is suggested that the methods used in measuring corrosion could be applied to wear.—R. A. R.

Automatic Coercive-Force Meter for Controlling the Quality of Thermal and Thermochemical Treatment of Steel Products. M. N. Mikheev. (Zavodskaya Laboratoriya, 1949, vol. 15, Feb., pp. 173–175). [In Russian]. A circuit diagram, photograph, and detailed account are given of a compact, automatic coercive-force meter designed for the control of the quality of the cementation and heat-treatment of steel products. The apparatus, constructed for working with 240 V., A.C., is caused to operate by the weight of the specimen when this is placed in position, and it can make about 900 tests/hr. with small specimens. Calibration of the apparatus is carried out using test-pieces of known hardness and depth of cementation. This type of coercive-force meter is stated to have given satisfactory service in the testing of large components of a chromium–nickel–molybdenum steel.—S. K.

The Magnetic Properties of Stainless Steel. W. A. Stein. (Electrical Engineering, 1949, vol. 68, Mar., p. 204). This is a summary of a paper read before the American Institute of Electrical Engineers. An investigation of the magnetic properties of six stainless steels is reported. The tests were performed over a range of − 70° to 600° F. and the analysis included D.C. and A.C. magnetization curves, hysteresis loops, and core losses. It is concluded that the smaller the percentage of chromium present, the more magnetic the stainless steel will be. Steels with a low chromium content of 12% to 13% had a much higher residual magnetism. Steels can tolerate up to 2% or 3% nickel without detriment to their magnetic characteristics. If over 8% nickel is present the steels are non-magnetic. The product of the residual magnetism and the coercive force is considerable, and hence stainless steels make fair permanent magnets. J. C. R.

The Non-Destructive Testing of Steel Castings and Forgings. J. Rhodes, T. H. Arnold and H. S. Peiser. (Transactions of the Institute of Marine Engineers, 1949, vol. 61, Mar., pp. 33–44). The various methods of non-destructive testing are described. These include: Proof-loading tests, metallographic methods of detecting surface defects; radiography using X-rays or gamma-rays; magnetic, fluorescent, and ultrasonic methods of crack detection; and magnetic and electrical tests. X-ray crystallography is also discussed, although it is not primarily used as a method of non-destructive testing.—R. F. F.

Testing by Ultrasonics. S. Y. White. (Audio Engineering, 1947, vol. 31, Nov., pp. 28–39: [Abstract] Centre de Documentation Sidérurgique, Bulletin Analytique, 1948, vol. 5, Nov., p. 52). Methods of utilizing ultrasonics by reflection, by measurement of speed, and by damping are described. Their application in the detection of defects in metal parts, and the measurement of the temperature of molten metals is discussed.

The Supersonic Reflectoscope. R. H. Frank and R. W. Renner. (American Institute of Mining and Metallurgical Engineers, Proceedings of the 31st National Open Hearth Conference, Apr., 1948, pp. 299–306). The principles of the supersonic reflectoscope for detecting flaws in steel are described and the manner in which defects of different size, shape, and position occur is shown in a series of 24 diagrams. R. A. R.

Detection of Flat Defects in Welded Structures. G. A. Homès. (Revue de la Soudure/Lastijdschrift, 1948, vol. 4, No. 4, pp. 210–222). The author describes ultrasonic methods of testing, and discusses their application in locating flat defects in welded materials.—R. F. F.

Flaw Detection by Ultrasonic and Other Non-Destructive Methods. A. C. Rankin. (Journal of the West of Scotland Iron and Steel Institute, 1947–48, vol. 55, pp. 69–118). *See* Journ. I. and S.I., 1948, vol. 158, Apr., p. 537.

Testing Materials by Ultrasonics. J. Ružek. (Svařování, 1948, vol. 8, Sept., pp. 106–109). [In Czech]. Ultrasonic waves propagate only in straight lines and are reflected by changes in the density of the medium. These properties are utilized to detect faults in materials. A pulsating generator produces 0·5 to 5 megacycle signals which are emitted for very short periods (1 to 10 microseconds). The impulses are transformed into mechanical waves by a crystal which is placed and moved over the part. The mechanical waves reflected from the opposite wall, or by a defect inside the part, are transformed by the same crystal into electrical waves and amplified by a suitable electrical circuit. Both the emitted and the reflected waves appear on a cathode-ray oscillograph as vertical lines, and the distance between these two lines is directly proportional to the distance of the reflecting surface from the crystal. To facilitate inspection of welds "angle ray" crystal arrangements have been developed, which cause the waves to enter the specimen at an angle suitable for the purpose. The ultrasonic instruments are very compact and are particularly useful for testing fatigue-stressed shafts. They can also be calibrated for measurement of wall thicknesses, and the circuit can be adjusted to "ignore" small permissible faults. A number of non-metallic materials can be also be tested with them—E. G.

Experimental Work Employing Radioisotopes Cobalt and Selenium. D. McCutcheon. (Non-Destructive Testing, 1948, vol. 7, Winter Issue, pp. 7–14). The procedure for purchasing radioactive isotopes from the U.S. Atomic Energy Commission is described and details are given of recommended radiation-absorption tests. Finally, some industrial applications, including the use of Cobalt 60, and a Geiger counter to follow the changes in the level of liquid metal in a cupola, are described.—R. A. R.

Artificial Radio-Active Elements in Metallurgy. P. Sue. (Société Française de Métallurgie, Oct. 18, 1948: Revue de Métallurgie, Mémoires, 1949, vol. 46, Feb., pp. 72–87). The use of radioactive tracers in solving problems of diffusion and oxidation, in investigating surface conditions, friction and lubrication, flotation, steelmaking and heat-treatment processes, and in metallurgical analysis is surveyed. A bibliography of recent articles is appended.—A. E. C.

Centrifugal Method of Investigating the Strength of Metals and Alloys at High Temperatures. I. I. Kornilov. (Zavodskaya Laboratoriya, 1949, vol. 15, Jan., pp. 76–82). [In Russian]. A testing method is described in which rod-shaped specimens are fixed vertically on the circumference of a vertical shaft which can be rotated with a constant, known speed. The specimens are fixed to the shaft by their upper ends and tend to be bent by the centrifugal force which acts upon them when the shaft is rotated, the amount of bending being an indication of the strength of the specimen. By enclosing the specimens and the lower part of the shaft in a furnace, the strengths at high temperature of a large number of specimens can be simultaneously measured and, since an oxidizing atmosphere can be provided, the results can give valuable indication of behaviour under service conditions. Results obtained for a number of steels and alloys are given, and their interpretation is discussed.—S. K.

Recent Developments in Methods of Hot Mechanical Tests. A. M. Borzdyka. (Zavodskaya Laboratoriya, 1949, vol. 15,

Jan., pp. 70–75). [In Russian]. Recent developments in four types of mechanical tests at high temperature are considered. First, tests in which the specimen is stretched at a controlled speed are dealt with, the apparatus and automatic recording device being described and some results obtained on testing a molybdenum steel being given. Next, apparatus and technique for creep tests at comparatively high temperatures (800° to 1000° C. and over) are outlined for loaded bar or wire specimens, and a method for bend creep testing at such temperature is also given. The article concludes with a brief review of relaxation tests at high temperature, two types of testing machine being discussed.—S. K.

A New Method for the Study of Relaxation in Steel Wires. M. G. Dawance. (Annales de l'Institut Technique du Bâtiment et des Travaux Publics, 1948, No. 9, Feb., pp. 1–8: [Abstract] Applied Mechanics Reviews, 1948, vol. 1, Oct., p. 262). The author describes a new method, applied by the Institut Technique du Bâtiment et des Travaux Publics, Paris, for studying relaxation (creep under constant elongation) in steel wires used for prestressed concrete constructions. The steel wires are stressed on strong steel frames, and anchored at their ends. The stresses in them are determined from time to time by means of an electro-acoustical method which measures the pre-vibration frequencies of the wires with the use of Coyne's 'Témoin sonore.' The influence of the flexural rigidity of the wires on their free vibration frequencies is taken into consideration. The stress is determined to an accuracy of 1%. The method is very simple and requires little test material so that no special precautions are required for conserving it. The results of some relaxation tests on steel wires with diameters varying from 2 to 5 mm. are reported and discussed.

The Creep Phenomenon in Metals. J. N. Greenwood. (Australasian Engineer, 1948, Dec. 7, pp. 78–83). The fundamentals of the creep of metals are examined. Evidence leading to three generalizations is cited, namely (*a*) at any temperature there is a minimum stress below which creep will not occur, (*b*) the lower the temperature, the higher will be the relative magnitude of the stress necessary to cause creep, and (*c*) for any given metal, a certain minimum temperature must be exceeded before creep will occur. The characteristics of deformation below and in the creep field of temperature, deformation within crystals, movement at crystal boundaries, intercrystalline cracking, and the use of lead as an experimental material for investigating creep are studied.—R. A. R.

High Creep Strength Austenitic Gas Turbine Forgings. D. A. Oliver and G. T. Harris. (Transactions of the Institute of Marine Engineers, 1947–1948, vol. 59, pp. 79–95). *See* Journ. I. and S.I., 1947, vol. 157, Oct., p. 309.

A Comparison of Some Carbon Molybdenum Steels on the Basis of Various Creep Limits. A. E. Johnson and H. J. Tapsell. (Proceedings of the Institution of Mechanical Engineers, vol. 159, pp. 165–172). *See* Journ. I. and S.I., 1948, vol. 160, Dec., p. 448.

Effect of Cold on the True Rupture Stress and the Deformability of Steel Containing Hydrogen. P. Bastien and P. Azou. (Comptes Rendus, 1949, vol. 228, No. 16, Apr. 20, pp. 1337–1339). Curves relating the true stress to the reduction of area (rational tensile curves) were determined for an annealed 0·15% carbon steel between + 15° and − 70° C. The steel specimens contained either no hydrogen or else were charged with this gas either by electrolysis for 48 hr. in a 10% HCl solution, or by chemical attack in this reagent. There was no difference in the effects of charging the specimens with hydrogen by these methods, once a certain degree of saturation had been reached. The results confirmed the small effect of absorbed hydrogen on the classic breaking stress and its adverse effect on the necking and elongation. Between + 15° and − 70° C. the true breaking stress was decreased steadily by hydrogen; it increased with increasing cross-sectional area in uncharged steels and decreased with increasing section in hydrogen-charged steels. Hydrogen-charged steels broke with a brittle fracture, uncharged steels with a semi-brittle fracture. The fractures had two zones, the one central, circular, brilliant, granular, and almost flat, the other annular, mat, fibrous, and in the shape of a truncated cone; the former corresponded to fracture by decohesion, the latter to fracture by slipping. The area where decohesion had occurred increased by steps as the testing temperature decreased; this apparently was connected with the three active slip planes {110} {112} and {123} in ferrite. At room temperature all three planes were active, but at low temperature only the {110}; in between were transition stages.

A. E. C.

Brittleness in Steels Produced by the Absorption of Hydrogen during Electrolytic Pickling. G. Bianchi and R. Zoja. (Ricerca Scientifica, 1948, vol. 18, Jan.–Feb., pp. 101–102: [Abstract] Chimie et Industrie, 1949, vol. 61, Mar., p. 262). The absorption of cathodic hydrogen affects elasticity, and the study of pickling embrittlement of steels using this characteristic is more precise and suitable than methods previously studied. A sharply defined effect is obtained by the addition of 0·03% $HgCl_2$ to the 10% solution of $NaCO_3$ and this confirms the specific action on the absorption of cathodic hydrogen caused by the addition of mercuric salts. The majority of tests were carried out at a temperature of 85°, as at that temperature the loss in elasticity is considerable. As current increases, there is a decrease in elasticity to a minimum, after which it regains its initial value and remains practically constant. No relation has been established between the chemical composition of a steel and the sensitivity of its elasticity to pickling embrittlement.

The Hardenability Effect of Molybdenum. J. M. Hodge, J. L. Giove, and R. G. Storm. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 2520: Journal of Metals, 1949, vol. 1, Mar., Section 3, pp. 218–227). This investigation was undertaken to establish the mechanism governing differences in the hardenability effect of molybdenum in nickel and in chromium steels. End-quench hardenability and isothermal transformation tests were made on two series of steels of varying molybdenum content, one series containing 3% of nickel and the other containing 1% of chromium. A content of 0·32% of molybdenum had a hardenability effect based on end-quench tests, twice as effective in the nickel steel as in the chromium steel. The hardenability effect of molybdenum in both steels and the difference in its effect in the presence of nickel and chromium are quantitative reflections of its effect on the rate of transformation at the temperature of the 'bainite nose' on the S-curve. The hardenability effect in the presence of either nickel or chromium was found to be unaffected by changes in austenitizing temperature over the temperature range of 1600° to 2000° F. The explanation of the difference in the effect of molybdenum on transformation rates to bainite in the presence of nickel or chromium was not apparent, but it did not seem to reflect differences in the rate of carbide solution in the two types of steel. An appendix is included on the calculation of hardenability values from end-quench and isothermal data.—J. C. R.

Effect of Boron on the Hardenability of High-Purity Alloys and Commercial Steels. T. G. Digges, C. R. Irish, and N. L. Carwile. (Journal of Research of the National Bureau of Standards, 1948, vol. 41, Dec., pp. 545–574). A study was made of the action of boron in relation to the hardenability of high-purity alloys varying in carbon content. The efficacy of boron in enhancing the hardenability of these alloys of certain steels is believed to be due to its action in retarding the rate of nucleation of ferrite and carbide while in solid solution in austenite. The hardenability of the boron-treated alloys, as determined in terms of the critical cooling rate of small specimens austenitized at a wide range of temperatures, varied with the prior history and with the carbon content. The hardenability of a commercial boron-treated steel, as determined by the end-quench test, was also sensitive to previous thermal treatments. Boron was lost in the decarburized zone of commercial steels, and its rate of diffusion apparently is of the same order of magnitude as that of carbon. The heat-treatment of specimens of the alloys and steels to produce a boron constituent and the microstructures of the alloys as cast and as homogenized are described.

Progress in Titanium Told at Naval Research Symposium. T. C. Du Mond. (Materials and Methods, 1949, vol. 29, Feb., pp. 45–47). The U.S. Office of Naval Research recently sponsored a symposium on titanium which was held at Washington. Some of the information from the 17 papers presented is given in this summary.—R. A. R.

The Influence of Small Contents of Lead on the Ability to Forge and Roll Austenitic Stainless Steels. S. Bergh. (Iron and Steel Institute, 1949, Translation Series, No. 376). *See* Journ. I. and S.I., 1948, vol. 160, Oct., p. 232.

Substitute Russian Steels for Stamping Dies and Permanent Moulds. G. L. Livshits. (Centre de Documentation Sidé-

rurgique, Circulaire d'Informations Techniques, 1949, vol. 6, Jan., pp. 10–14). This is an abridged translation into French of a paper which originally appeared in Russian in Stal, 1948, No. 2, pp. 153–156. (*See* Journ. I. and S.I., 1948, vol. 159, July, p. 342).

Steels and Their Treatment. N. N. Brown. (Machine Design, 1948, vol. 20, Oct., pp. 87–92, 152–154; Nov., pp. 110–116, 190–192). The selection and characteristic properties of steels according to American Iron and Steel Institute specifications for gears, pinions, and many other purposes are discussed in Part I and the selection of a heat-treatment to produce the desired properties is dealt with in Part II.—R. A. R.

METALLOGRAPHY

The Use of Addition Agents in Etchants for Special Effects. I. R. Lamborn. (Australian Institute of Metals: Steel Processing, 1949, vol. 35, Feb., pp. 86–89). Etchants for revealing temper brittleness and for general metallographic requirements are discussed with several references from earlier papers on Teepol and Zephiran chloride with and without additions.—R. A. R.

Electron-Microscopic Investigation of the Structure of Steel. N. N. Buinov and R. M. Lerinman. (Zavodskaya Laboratoriya, 1949, vol. 15, Feb., pp. 167–170). [In Russian]. In the investigation described, an electron-microscope with a resolving power of 30 Å. was used to study the surfaces of various steels. A 1% solution of collodion in amyl acetate was used for making the replicas of the surfaces, the replicas being photographed at magnifications of 7000 dia. The technique for the polishing and etching of the surface was similar to that used in connection with the highest magnifications of ordinary microscopy. Among the structures illustrated are those of the following steels: Ordinary eutectoid: high-speed; chromium–nickel–molybdenum; high-carbon; hardened ball-bearing; chromium–manganese. The results are discussed, and some ordinary photomicrographs of the same surfaces are shown for comparison.—S. K.

Magnetic Method for the Study of the Structure of Austenitic Steels. S. Bergh. (Centre de Documentation Sidérurgique, 1949, Traduction No. 587). This is a French translation of an article which appeared in Jernkontorets Annaler, 1948, vol. 132, No. 4, pp. 105–109 (*see* Journ. I. and S. Inst., 1948, vol. 159, Aug., p. 454).

Contribution to Research on the Black Spots in Malleable Iron. F. Vogel. (Neue Giesserei, 1949, vol. 36, Feb., pp. 45–47). An investigation of the composition of the black spots found in malleable iron castings is reported. Areas containing spots were chipped out of several castings and carefully dissolved in dilute HCl. Analyses were made of the residue and calculations showed that this consisted of iron oxide 92·21%, iron 1·28%, silicon 5·68%, and carbon 0·92%. The conclusion is that, apart from slag inclusions, these black spots do not consist of ferrous oxide and iron sulphide, but are products of a reaction between molten iron and silica from particles of moulding sand, or from an aluminium silica reaction when aluminium is added to deoxidize the metal. There was evidence that a carbide with the composition FeC_2 was formed.—R. A. R.

Precipitation Phenomena in the Solid Solutions of Nitrogen and Carbon in Alpha Iron below the Eutectoid Temperature. L. J. Dijkstra. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 2540: Journal of Metals, 1949, vol. 1, Mar., Section 3, pp. 252–260). Precipitation of carbon and of nitrogen from solid solution in α-iron was studied at different temperatures by internal friction measurements. In the case of nitrogen these measurements suggested the presence of two successive stages in precipitation. This suggestion was verified by metallographic examination. In the first stage plates of an unknown precipitate are formed on the (100) planes of the matrix. During the second stage Fe_4N plates are formed. The unknown phase appears to be less stable than Fe_4N, but cannot be considered as a transition state of Fe_4N. The rate of precipitation was low at low temperatures, low at high temperatures near the critical temperature, and at a maximum rate in an optimum temperature range. Plastic deformation (studied only in the case of nitrogen) was found not only to increase the rate of precipitation, but also to lower the final solution concentration presumably in equilibrium with the precipitate. It appeared that the precipitate induced by plastic deformation was not identical with that which formed in annealed material. This viewpoint was confirmed by metallographic examination which failed to reveal visible precipitates even after the final equilibrium solute concentration had been attained.

Recrystallization and Microstructure of Aluminium Killed Deep Drawing Steel. R. L. Rickett, S. H. Kalin, and J. T. Mackenzie, jun. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 2552: Journal of Metals, 1949, vol. 1, Mar., Section 3, pp. 242–251). Recrystallization of aluminium-killed low carbon steel, both at constant temperature and on continuous heating, was investigated and compared with that of rimmed steel to determine the mechanism of the formation of elongated grain. At constant temperature recrystallization of aluminium-killed steel of the elongated grain type takes place in three distinct stages: (1) An initial period resembling the start of recrystallization in rimmed steel; (2) a second period during which recrystallization proceeds very slowly; and (3) comparatively rapid recrystallization of the remaining portion. The length of time required for complete recrystallization is ordinarily much greater for aluminium-killed steel than for rimmed steel at a comparable temperature. In the isothermal recrystallization of aluminium-killed steel, increase in temperature increased the amount of recrystallization which took place in the initial stage and shortened the other stages, and made the grain-size finer and more nearly equiaxed.—J. C. R.

The Definition of Metal. Z. Jasiewicz. (Hutnik, 1948, vol. 15, Dec., pp. 523–527). [In Polish]. The crystalline structures of the metallic elements are reviewed and conclusions about the properties of metals are drawn from the electron distribution.—W. J. W.

Recent Work on Transformations in High Speed Steels. A. Michel. (Bulletin du Cercle d'Études des Métaux, 1948, vol. 5, Dec., pp. 137–167). An account is given of the present state of knowledge on transformations in high-speed steels according to the published work of various investigators. J. C. R.

Determination of an Isothermal Transformation Diagram with an Optical Dilatometer. J. K. L. Andersen. (Journal of The Iron and Steel Institute, 1948, vol. 162, May, pp. 29–32). An account is given of the determination of the isothermal transformation diagram for a nickel–chromium die steel, using a recording Leitz dilatometer equipped with a revolving casette. With this device accurate measurements of the elongation as a function of time of the undercooled austenite was made possible. Records of the isothermal transformation diagrams in a form convenient for filing were obtained.

Experiences in the Study of Isothermal Transformations. T. F. Russell and C. Mavrocordatos. (Journal of The Iron and Steel Institute, 1949, vol. 162, May, pp. 33–43). Part I describes an apparatus for exploratory work on isothermal transformation of slowly reacting steels by the magnetic method. Self-recorded diagrams showing temperature and magnetic change in transformations requiring hundreds of hours have been obtained. The apparatus revealed, many years ago, the remarkable stability of the austenites of some steels at temperatures between the pearlite range and the intermediate range, and the stability of partial transformation in the latter range. The apparatus also has limitations. It is shown, for example, that the austenite of a 3% chromium steel may change completely to pearlite in the non-magnetic condition.

In Part II the coefficients of thermal contraction of a number of austenites down to temperatures near the M_s points are given, and the change of length of the specimen during isothermal transformation is recorded for a number of hypo- and hyper-eutectoid steels. The predominating effect of carbon on these changes of length is discussed, and the relation of the final length to that of an aggregate of ferrite and carbide is shown.

The Acceleration of the Rate of Isothermal Transformation of Austenite. M. D. Jepson and F. C. Thompson. (Journal of The Iron and Steel Institute, 1949, vol. 162, May, pp. 49–56). Part I describes the effect of a fluctuating temperature of the transformation bath, a marked decrease in the transformation time being observed in the martensite range. Most of the transformation occurs during the cooling part of the temperature cycle. Part II deals with the effect of stress on the rate of isothermal transformation which has

been examined over a range of temperatures, both tensile and compressive stresses being investigated. Tensile stresses of the order of 10 tons./sq. in. are found to accelerate markedly the decomposition of austenite at constant temperature. Compressive stresses of a higher order seem to be required to produce a comparable effect. Below a certain minimum stress, little or no acceleration occurs, and the increase in the rate of transformation becomes greater as the stress is increased. Stresses of a fairly high order are shown to have an effect on the distribution of low temperature bainite. A simple, rapid, and sufficiently accurate method of following the course of the transformation, by measuring the load required to break notched test-pieces, is described.

CORROSION

Factors of Importance in the Atmospheric Corrosion Testing of Low-Alloy Steels. H. R. Copson. (Proceedings of the American Society for Testing Materials, 1948, vol. 48, pp. 591–609). *See* Journ. I. and S.I., 1948, vol. 159, Aug., p. 458.

Atmospheric Durability of Steels Containing Nickel and Copper—Additional Exposure Data. N. B. Pilling and W. A. Wesley. (Proceedings of the American Society for Testing Materials, 1948, vol. 48, pp. 610–617). *See* Journ. I. and S.I., 1948, vol. 159, Aug., p. 458.

Laboratory Corrosion Tests of Iron and Steel Pipes. G. A. Ellinger, L. J. Waldron, and S. B. Marzolf. (Proceedings of the American Society for Testing Materials, 1948, vol. 48, pp. 618–627). *See* Journ. I. and S.I., 1948, vol. 159, Aug., p. 458.

Station Design and Material Composition as Factors in Boiler Corrosion. R. B. Donworth. (Proceedings of the American Society for Testing Materials, 1948, vol. 48, pp. 897–906). *See* Journ. I. and S.I., 1949, vol. 161, Feb., p. 167.

Corrosion in the Power Industry. I. C. Dietze. (Corrosion, 1948, vol. 4, Nov., pp. 566–567). A plastic paint has been successfully used to prevent the corrosion of condenser tubes through which sea water from Los Angeles harbour flows. This water is contaminated with sewage and industrial wastes. The rate of heat transfer decreased at first, but after ten days it was as good or better than that of the original tubes.

Somastic Pipe Coating and Cathodic Protection. G. N. Scott. (Proceedings at First Annual Meeting of the National Association of Corrosion Engineers, Apr., 1944, pp. 238–245). Good protection against corrosion of buried pipelines is obtained by a continuous coating of Somastic and almost perfect protection is obtainable by supplementing this with cathodic protection. This paper discusses the current requirements and design of cathodic protection systems for this purpose.—R. A. R.

Methods for the Prevention of Hydrocyanic Acid Corrosion of High-Pressure Gas Vessels. C. Eymann. (Gas- und Wasserfach, 1948, vol. 89, No. 6, pp. 183–187 : [Abstract] Chimie et Industrie, 1949, vol. 61, Feb., p. 149).

Corrosive Attack by Motor Fuels. P. Schläpfer and A. Bukowiecki. (Schweizer Archiv, 1948, vol. 14, Sept., pp. 257–274). The corrosion of metals by motor fuels was investigated with special reference to the effects of acid and water in the fuel. With fuels free from water, small quantities of acid play an important part. With acid in alcohols, the intensity of attack diminishes with increasing molecular weight of the alcohol. Under certain conditions water in the fuel may separate out on to the surface of the metal and give rise to electrochemical corrosion. With the same water content the attack increases with increasing polarity of the fuel. The motor fuels are classified into groups according to their corrosive effect.—R. A. R.

Topochemistry and the Kinetics of Corrosion Phenomena. W. Machu. (Archiv für Metallkunde, 1949, vol. 3, Jan., pp. 1–7). A theory for corrosion is put forward and it is shown that the most important factor affecting corrosion protection and corrosion rate is the stability and extent of the surface of the cathode. A relationship between changes in the cathode surface and time is found, and confirmed by several examples. The rate of corrosion of a coated metal is not proportional to the surface of the dissolving anode, but to the cathode area. The time factor is governed by the instability of the coating and the manner with which depolarization of oxygen or discharge of hydrogen ions can proceed at the local cathodes. The value of the velocity constant k is an accurate measure of the strength and velocity of attack on a coated metal.—R. A. R.

Galvanic Action between Lead, Worthite and other Acid-Resistant Alloys in Sulphuric Acid. W. E. Pratt and E. T. Collinsworth, jun. (Electrochemical Society : Corrosion, 1949, vol. 5, Feb., pp. 39–44). Investigations were made on the mechanism involved in the changes of the relative potentials of lead, and some stainless steels, notably Worthite, in H_2SO_4 as an electrolyte. When 66° Bé H_2SO_4 was poured into water without adequate mixing, the temperature rose to 240° F. and the solution corroded the Worthite (an alloy of Fe 48%, Ni 24%, Cr 19%, Mo 3%) pump which was used. Fitting a perforated lead pipe in the diluting tank, and blowing in air, mixed and cooled the liquid and prevented corrosion of the pump.—R. A. R.

Anodic and Cathodic Polarisation Curves for Iron and Copper in Sulphate Solutions with Additions of Oxidising Agents. N. D. Tomashov, G. P. Sinel'shchikova, and M. A. Vedeneeva. (Comptes Rendus (Doklady) de l'Académie des Sciences de U.R.S.S., 1948, vol. 61, Aug. 1, pp. 669–672 : [Abstract] Bulletin of the British Non-Ferrous Metals Research Association, 1949, Mar., p. 114). The authors give anodic polarization curves for iron in NaCl solutions, and in solutions of Na_2SO_4 (with and without additions of H_2O_2 or $K_2Cr_2O_7$). The cathodic curves for copper are not shown, but the results are applied to the study of the mechanism of the corrosion of copper and steel.

Mitigation of Corrosion on City Gas Distribution Systems. A. D. Simpson, jun. (Corrosion, 1949, vol. 5, Feb., pp. 59–69). Experience gained in the use of cathodic protection for gas distribution systems in Texas and Louisiana is reported. R. A. R.

Experimental Study of the Resistance of Different Steels to Erosion by Cavitation. S. Saito. (Centre de Documentation Sidérurgique, 1948, Traduction No. 576 ; Circulaire d'Informations Techniques, 1948, vol. 5, Dec. 15, pp. 505–521). This is a translation into French from Japanese of a paper which originally appeared in Transactions of the Society of Mechanical Engineers of Japan, 1943, vol. 9, Nov., pp. III 57–III 62). An account is given of tests with four steels used for ships' turbines to determine their resistance to erosion. The method of testing is described and the results obtained are presented in graph form.—J. C. R.

On the Interpretation of Cavitation Corrosion Phenomena. G. Petracchi. (Metallurgia Italiana, 1949, vol. 41, Jan.–Feb., pp. 1–6). The principal suggestions put forward to explain the corrosion by cavitation and the ideas on which testing instruments used by research workers are based, are reviewed. The author advances his theory that the cause of corrosion by cavitation is the action of mechanical stresses, which increase the corrosive effects of microcells. Using the results of experiments carried out on various metals in support of his hypothesis, the author shows the dominant effect of very weak currents, which have a cathodic protecting effect. R. F. F.

A Geographical Study of Deposits and Corrosion. F. N. Alquist. (Corrosion, 1949, vol. 5, Feb., pp. 45–53). The paper reports the results of investigations of 143 samples of deposits from boilers, condensers, and pipelines in ten States of the U.S.A. Methods are outlined by which plant personnel can determine the extent of corrosion and deposits caused by industrial waters.—R. A. R.

Stress Corrosion. A Review of the Literature. K. R. Hanna. (Australia, Council for Scientific and Industrial Research Division of Aeronautics, 1948, Report S.M. 120 : [Abstract] Bulletin of the British Non-Ferrous Metals Research Association, 1949, Mar., p. 114). This review includes examples of stress-corrosion ; nature of stresses ; effects of stress on electrode potentials of metals ; alloy characteristics influencing stress-corrosion, including properties of grain boundaries, minor constituents, film formation, and breakdown ; methods used to prevent or minimize stress-corrosion ; and methods of testing and investigation. There are 28 references.

ANALYSIS

Determining Small Amounts of Carbon in Steel. H. H. Uhlig and J. J. Naughton. (Steel, 1949, vol. 124, Jan. 31, pp. 60–61, 74, 78). The low-pressure combustion method is described. The sample is burned in oxygen at a pressure of 15–20 cm. of mercury in a beryllia or alumina crucible contained inside a platinum crucible heated by high frequency. The carbon dioxide is collected on a trap cooled by liquid

nitrogen, and determined by pressure measurement in a calibrated volume. The method is stated to give greater accuracy for low-carbon steels than the standard method, and to be equally accurate on both low and high carbon contents.—J. P. S.

Rapid Determination of Carbon Content in Steels. P. A. Haythorne and B. R. Payne, jun. (Machinist, 1949, vol. 92, Apr. 23, pp. 1738–1739). A method of determining the approximate carbon content of a steel, from the hardness of a specimen after quenching from above the critical temperature, is described and a curve is given showing the relation between Rockwell C hardness and carbon content.—R. F. F.

Determination of Cobalt by the Volume of Precipitate. I. M. Korenman and E. M. Punchik. (Zavodskaya Laboratoriya, 1949, vol. 15, Feb., pp. 134–135). [In Russian]. The determination of cobalt in the presence of relatively large quantities of nickel by measuring the volume of the precipitate of dipotassium sodium cobaltinitrite is briefly described and said to be satisfactory—S. K.

On the Determination of Moisture and Molybdenum in Unroasted Molybdenum Concentrates. M. V. Babaev. (Zavodskaya Laboratoriya, 1949, vol. 15, Feb., pp. 237–238). [In Russian]. An account is given of experiments in which it was shown that the use of incorrect heating temperature in the analysis of unroasted molybdenum concentrates leads to errors due to the presence of oils remaining from the flotation process. It is recommended that the drying should be carried out for 2 hr. at a temperature below 110° C., and the oil then removed either by extraction or by heating at 300–310° C. for the same time.—S. K.

Quick Method for the Determination of Manganous Oxide. A. M. Charova and E. B. Rutenburg. (Zavodskaya Laboratoriya, 1949, vol. 15, Feb., p. 241). [In Russian]. Results obtained by three different methods for the determination of manganous oxide in iron ores, blast-furnace flue dust, slags, and agglomerate are compared, and a rapid method for this determination is briefly described.—S. K.

Variations of the Blackening of Spectrum Lines of Industrial Alloys during Heat Treatment. J. M. Lopez de Azcona and A. Camunas Puig. (Groupement pour l'Avancement des Méthodes d'Analyse Spectrographique des Produits Métallurgiques, 10th Congress, June, 1948, pp. 55–64). Certain lines of the spark spectra between two rod electrodes were observed through a radial hole in a small cylindrical furnace, while the samples were being heated or cooled slowly. The line density differences, when plotted against temperature, show striking variations. Those for carbon in steel are plotted for 0·4%, 0·62%, and 0·72% of carbon. On heating, the relative intensity of the carbon line (2296) shows a maximum at about 100° C., and a steep fall to a minimum at about 500° C., with two further slight maxima. The cooling curve has more marked changes of direction but a smaller range, and here the changes may be correlated with the usual arrest points Ar_0 and Ac_1.—E. VAN S.

Rapid Colorimetric Method for the Determination of Tungsten in Steel. A. G. Bogdanchenko and A. D. Sapir. (Zavodskaya Laboratoriya, 1949, vol. 15, Jan., pp. 11–15). [In Russian]. Details are given of a method for the determination of tungsten in steel by colorimetric examination of a solution in which this element is present as the thiocyanate complex. The colorimetric standard solution is prepared by mixing 100 ml. of 20% ammonia with a solution of 0·76 g. of ammonium dichromate in 500 ml. of water and making up to 1 litre with water, the colour thus produced being stable for several months. The method fails in the presence of large quantities of molybdenum or antimony and in the presence of vanadium or chromium, but is virtually unaffected by arsenic.—S. K.

Application of the Duplication Method for the Colorimetric Determination of Tungsten. Iu. A. Chernikhov and R. S. Tramm. (Zavodskaya Laboratoriya, 1949, vol. 15, Jan., pp. 15–20). [In Russian]. An experimental investigation is described which was undertaken to see under what conditions the colorimetric determination of tungsten could be carried out by the duplication method rather than by the more complicated procedures such as the standard series method. It was found that duplication could give satisfactory results when the stability of the cyanotungsten complex was secured and that its sensitivity could be increased by extraction with isoamylalcohol to an extent sufficient for the determination of 0·00001% of tungsten. Molybdenum contents less than one-tenth of the tungsten content did not interfere with the determination, and larger contents could be satisfactorily allowed for. Iron had no effect on the simple determination, but in the case of extraction being used, had to be removed by extraction with ether.—S. K.

The Determination of Molybdenum in Alloy Steels by the Photocolorimeter. A. A. Tikhonova. (Zavodskaya Laboratoriya, 1949, vol. 15, Jan., pp. 107–108). [In Russian]. The photocolorimetric determination of 0·2% to 0·8% of molybdenum in steels containing 0·6% to 14·4% chromium is described, the results being compared with those obtained by a colorimetric method; they are shown to be in good agreement.—S. K.

The Determination of Molybdenum and Titanium in Ferro-Alloys and Steels. P. Ya. Yakovlev and E. F. Penkova. (Zavodskaya Laboratoriya, 1949, vol. 15, Jan., pp. 34–36). [In Russian]. The method described for the determination of molybdenum in ferro-alloys and steels is based on the precipitation of the iron by sodium hydroxide, followed by reduction by zinc amalgam of the sulphuric acid solution of molybdenum and its titration with permanganate. Methylene blue solution can also be used for the titration, no precipitation of iron being required in this case. The procedure given for the determination of titanium is based on the reduction of this element to the trivalent state by zinc amalgam, followed by titration with ferric chloride in the presence of the thiocyanate of potassium or ammonium. Both the above titrations must be carried out in an atmosphere of carbon dioxide.—S. K.

A Quick Method for the Determination of Titanium in Alloy Steels Containing Chromium and Nickel. Z. P. Gutkovskaya. (Zavodskaya Laboratoriya, 1949, vol. 15, Jan., pp. 109–110). [In Russian]. A modified colorimetric method for the determination of titanium is described in which provision is made for obviating the difficulty resulting from the coloured nature of nickel and chromium salts when these elements are present in the steel.—S. K.

The Determination of Oxygen in Steel. (Zeitschrift der Schweisstechnik. (Switzerland), 1948, vol. 38, Oct., pp. 213–214: [Abstract] Index Aeronauticus, 1949, vol. 5, Apr., pp. 52–53). Aluminium is introduced by diffusion annealing into the powdered steel sample; the quantity of aluminium oxide found is a measure of the oxygen content. The method is in use by the German testing establishment.

Trials with Electrolytic-Potentiometric Analyses. W. Oelsen and P. Göbbels. (Stahl und Eisen, 1949, vol. 69, Jan. 20, pp. 33–40). Electrolytic analysis of solutions is discussed and its advantages pointed out. An example is described in which manganese, vanadium, and iron in a single solution are determined by electrolytic reduction. Neutralizing processes can also be followed electrolytically and, as an example, the determination of sulphur in steel is described, the neutralizing of the sulphuric acid being followed by electrolysis.

R. A. R.

Note on Gold in Iron Ores. Precautions to be Taken to Reveal Its Presence. A. Riester. (Revue de Métallurgie, Mémoires, 1949, vol. 46, Jan., pp. 36–38). The author discusses the occurrence of gold and silver in iron ores and deposits of ancient iron scoria, the reasons why in some cases its detection is difficult, and precautions that may be taken to ensure accuracy of the assays.—A. E. C.

Analysis of Coals and Carbonaceous Materials Containing High Percentages of Inherent Mineral Matter. G. W. Himus and G. C. Basak. (Fuel, 1949, vol. 28, Mar., pp. 57–65). This paper describes experiments which have shown that if a sample of coal or oil-shale is divided into fractions yielding percentages of ash higher and lower than that of the original material, there is a linear relationship between the percentage ash and the content of carbon, hydrogen, nitrogen, and sulphur. Hence, by extrapolating to zero ash, the composition of the mineral-free organic matter may be determined. The hitherto unknown ratio of original mineral matter to ash may also be calculated. Attention is drawn to certain failures. It is shown that the use of a formula of the Parr type to calculate the mineral-matter/ash ratio may give rise to misleading or even absurd results.

Quick Method for the Determination of Moisture in Moulding Materials and Mixes. A. I. Bekhtereva. (Zavodskaya Laboratoriya, 1948, vol. 14, Dec., p. 1494). [In Russian]. The determination of moisture in moulding sands and similar substances by measuring the volume of acetylene evolved from the reaction of a weighed sample with calcium carbide is described.—S. K.

Thermoelectric Method for the Determination of Silicon in Certain Ferroalloys. P. D. Korzh. (Zavodskaya Laboratoriya, 1949, vol. 15, Feb., pp. 170–173). [In Russian]. An account is given of experiments in which the thermoelectric properties of blast-furnace ferrosilicon, ferromanganese, and silicomanganese were investigated. The concentrations of silicon in the above ferroalloys were 8–15%, 0·1–2·5%, and 5–20%, respectively, and it was found that this element could be satisfactorily determined by measuring the e.m.f. developed by a couple of Nichrome and a sample of the alloy. The best temperature for the hot junction was found to be 325° C., and calibration curves were plotted for this temperature showing the e.m.f. against silicon content, numerous analysed samples being used. Results obtained by the thermoelectric method are presented and compared with those of chemical analyses—S. K.

Correction in the Determination of Carbon in Ferrochromium. M. V. Babaev. (Zavodskaya Laboratoriya, 1948, vol. 14, Dec., pp. 1480–1486). [In Russian]. Standard Russian procedure for the determination of carbon in ferrochromium by the Wirtz-Strolein gas-volumetric method is critically examined in the light of experimental data which show that a single combustion is not sufficient for the conversion of all the carbon into carbon dioxide. Neglect of this fact is postulated as one reason for the low carbon contents frequently ascribed to ferrochromium by steelworks analysts, further reasons for divergent results being lack of proper calibration of the apparatus and failure to carry out adequate blank experiments. Attention is drawn to defects in the system used for the classification of ferrochromium according to its carbon content.—S. K.

Determination of Iron and Insoluble Residue in Ore without Using Mercuric Chloride and Phosphoric Acid. Iu. I. Usatenko and P. A. Bulakhova. (Zavodskaya Laboratoriya, 1948, vol. 14, Dec., pp. 1420–1421). [In Russian]. The following method is stated to be satisfactory for the determination of iron and insoluble residue in ores : 0·5 g. of the finely ground sample is moistened with water and digested at 70° C. with 15 ml. conc. hydrochloric acid, 1–2 ml. of stannous solution being added to facilitate the solution. When no dark particles remain, the liquid is brought to boiling point and the iron is reduced with stannous chloride solution. After adding a pinch of sodium bicarbonate and two drops of silicomolybdic acid, the liquid is titrated with dichromate to a grass-green colour. The liquid is cooled and titrated with standard dichromate after adding 40 ml. of 1 : 4 sulphuric acid and 1 ml. of a solution of phenylanthranilic acid, only the second titration being used in the calculation of the result. The end-point of this titration is indicated by the change of the colour of the liquid from green to reddish-brown. The liquid is boiled and filtered, the insoluble residue then being determined in the usual way.—S. K.

Determination of Ferrous Oxide in Chrome Ore and Chrome-Magnesite Refractories. H. P. Samanta and N. B. Sen. (Transactions of the Indian Ceramic Society, 1946, vol. 5, No. 3, pp. 97–100 : American Ceramic Abstracts, 1949, Jan. 1, p. 29). Present methods of FeO determination with non-oxidizing solvents and fluxes gave unreliable results in chrome-ore analyses. A modified Shein's method using V_2O_5 gave satisfactory results for FeO and Fe_2O_3 contents that checked with combustion methods. Fe_2O_3 contents of 8·72% to 20·2% were determined in ten samples of Bihar chrome ores, while the same ores calcined to 950° C. for 2 hr. and chrome magnesite brick analyses showed ferrous iron to be totally absent.

Determination of Alumina in Chrome Ore and Chrome-Magnesite Refractories. H. P. Samanta and N. B. Sen. (Transactions of the Indian Ceramic Society, 1946, vol. 5, No. 3, pp. 101–103 : American Ceramic Abstracts, 1949, Jan. 1, p. 29). A more rigorous method for the determination of Al_2O_3 than that generally employed for chrome ore and chrome-magnesite refractories shows that percentages of Al_2O_3 varying from 1·82 to 6·53 are retained in the residue left after the water extraction of the peroxide fusion. The higher Al_2O_3 residues are formed in material also higher in SiO_2 and MgO content.

Spectrographic Analysis of Alumina in Silica Brick. P. R. Irish. (American Institute of Mining and Metallurgical Engineers, Proceedings of the National Open Hearth Conference, 1948, vol. 31, pp. 143–156). A detailed account is given of a spectrographic procedure for determining alumina in silica bricks ; the time required is less than 30 min.—R. A. R.

Chemical Analysis of Heat Treating Salts. V. C. Petrillo. (Steel Processing, 1948, vol. 34, Dec., pp. 652–657, 666 ; 1949, vol. 35, Jan., pp. 37–43). The Chemical Testing Section of the Ordnance Laboratory, Philadelphia, has drawn up specifications for the permissible amounts of impurities and methods of analysing the following heat-treatment salts : (*a*) Nitrates and nitrites of sodium and potassium ; (*b*) sodium and potassium nitrates ; (*c*) sodium and potassium chlorides ; and (*d*) barium chloride and silica. The paper describes rapid and accurate chemical methods for determining silica in class (*d*) mixtures ; fluorides and carbonates in classes (*a*), (*b*), and (*c*) ; chlorides in classes (*a*) and (*b*) ; as well as *p*H ranges, matter insoluble in water, sulphates, and moisture in all four classes.

On the Effect of Certain Factors on the Determination of Sulphur in Heavy Oil Products. A. S. Eigenson and P. D. Yakhina. (Zavodskaya Laboratoriya, 1949, vol. 15, Feb., pp. 147–156). [In Russian]. Experiments are described on the results of which criticism is made of present methods of determining sulphur in fuel oil and other heavy petroleum products. Improved procedures for this determination are suggested.—S. K.

Determination of Total Sulphur in Heavy Oil Products. T. A. Zikeev and M. G. Shifrin. (Zavodskaya Laboratoriya, 1949, vol. 15, Feb., pp. 157–158). [In Russian]. Combustion with a mixture of manganese dioxide and soda in the ratio of 2 : 1 was found to be satisfactory for the determination of total sulphur in liquid heavy-petroleum products containing about 0·2–4% of this element, the results obtained agreeing well with those from bomb combustions.—S. K.

The Quantitative Determination of Dust in Gas. A. H. Arbogast. (Yearly Proceedings of the Association of Iron and Steel Engineers, 1948, pp. 762–769). *See* Journ. I. and S.I., 1949, vol. 161, Apr., p. 398.

A Mechanical Mortar. P. I. Shportenko. (Zavodskaya Laboratoriya, 1949, vol. 15, Jan., pp. 125–126). [In Russian]. A mechanically operated mortar is described, which, working at about 1 kW., can crush an average sample of cast iron, slag or ferrosilicon in 10 to 15 min., the time for a sample of ferrochromium being 90 min.—S. K.

ECONOMICS AND STATISTICS

Steel Production—Some Facts and Problems. L. Chapman. (Journal of the Institution of Production Engineers, 1949, vol. 28, Mar., pp. 120–128). Economic aspects of the British iron and steel industry are discussed with notes on the raw materials required to produce 15 million tons of ingots per annum, the organization of the industry, research, and prices in this and other countries.—R. A. R.

The Electrochemical and Electrometallurgical Industry of Norway. C. W. Eger. (Journal of The Iron and Steel Institute, 1949, vol. 162. May, pp. 13–15). The development of the electrochemical and electrometallurgical industry of Norway to its present-day proportions, since the beginning of the present century, has been made possible largely by the country's water-power resources and its many excellent ports. The country also has considerable mineral resources. The principal electrochemical and electrometallurgical plants, and their products, in the various industrial areas of Norway, are described, and it is concluded that further development of the industry can be expected when increased hydro-electric power is made available.

The Scrap Problem in Western Europe and Scandinavia. P. Michalowski. (Hutnik, 1948, Dec., vol. 15, pp. 547–555). [In Polish]. The deficiency of scrap in Western Europe and Scandinavia is discussed from the economic and metallurgical points of view.—W. J. W.

Revolutionary Progress of Science and Engineering in the U.S.S.R. I. Borejdo. (Hutnik, 1948, vol. 15, Oct.–Nov., pp. 434–437). [In Polish]. Some examples are given in which the progress of productivity due to mechanization is shown. In 1913 the 58 blast-furnaces in the south of Russia employing 10,600 men produced 3·1 million tons of pig iron. In 1945 the ten blast-furnaces of the two metallurgical combines (Magnitogorsk and Kuzniscow) with only 1300 men produced 4 million tons of pig iron. In 1945 the 38 open-hearth furnaces of these two metallurgical combines have produced 20% more steel than the former works in South Russia with 82 open-hearth furnaces, and 27 converters, employing two and a half times as many men.—W. J. W.

Iron and Steel Industry of U.S.S.R. and the Five-Year Plan 1946-1950. S. Wroblewski. (Hutnik, 1948, vol. 15, Oct.–Nov., pp. 438–460). [In Polish]. The five-year plan for the development of the iron and steel industry in U.S.S.R. is discussed. The accurate data describing the development of the industry are based mostly on a book written by J. P. Bardin and N. P. Bannyj. The development of the iron industry is shown in comparison with the production in 1913 and comprises the first, second and third five-year plans, i.e., 1927 to 1941. In the last period the production of steel exceeded 18 million tons. According to the fourth plan (1946–50), the production of steel has to exceed 25 million tons. To reach this target there will be put in commission 45 blast-furnaces, 165 open-hearth furnaces, 15 converters, 90 electric furnaces, 104 rolling mills, and 63 coke-oven batteries. The distribution of the industry throughout the country is considered, and sintering, rolling mills and tube production are discussed.—W. J. W.

BOOK NOTICES

DAVIES, M. "*The Physical Principles of Gas Liquefaction and Low Temperature Rectification.*" 8vo, pp. viii + 205. Illustrated. London, 1949: Longmans, Green and Co. (Price 25*s.*).

The production of this treatise has been inspired by the growing importance, from both the purely scientific and the industrial points of view, of practical methods of gas liquefaction and fractionation of gaseous mixtures. As its title implies, it deals with the thermodynamic principles rather than the practical operation of the various processes considered, and the treatment, therefore, is necessarily mathematical, but should be by no means outside the comprehension of the average qualified technologist. After an introductory chapter on elementary thermodynamics, the author goes on to consider simple cooling by adiabatic expansion, and compressed vapour refrigeration, leading up logically to Pictet's process. The various high-pressure air liquefaction processes, particularly the Linde process, are next analysed, and some quantitative operating data are given. In a chapter on isentropic expansion, an account is given of Kapitza's recent development of a turbo-expander and low-pressure liquefaction circuit. The author points out that the latter, although having the advantages of low capital cost and good power efficiency, has not, as Kapitza claims, an efficiency far exceeding that of any high-pressure installation. Further topics considered are heat exchangers and accumulation and rectification. The latter is dealt with very thoroughly, from both the practical and theoretical aspects, and the author does not lose sight of the importance of economic considerations in practical air-rectifying systems. The book concludes with some account of the application of the processes described to the separation of the inert gases from air, and to the treatment of fuel gases; the author attaches great importance to the latter, as a means of the most economic use of coal as a raw material.

Among the many excellent illustrations in this book are reproductions of charts giving accurate data on the thermodynamic properties of air at low temperatures, reproduced from the Transactions of the American Institute of Chemical Engineers. These are undoubtedly most useful, but it is unfortunate that the scales are in British units, whereas metric units are quite properly used elsewhere throughout the book. This, however, is a very minor criticism, and the book should be a welcome and timely addition to technical literature.—M. A. VERNON.

EYT, E. "*Les Laitiers Métallurgiques et leurs réactions.*" 8vo, pp. xv + 94. Paris, 1949: Dunod. (Price 960 francs).

This is a thesis presented by the author to the Faculté des Sciences de Paris in order to obtain the degree of Doctor; it concerns a theoretical consideration of metallurgical slags and their reactions. Dr. Eyt conducted his small-scale experiments in a single-phase electric-arc furnace with a capacity of 200 kg. Experiments were also carried out in industrial furnaces, *viz*: in a 35-ton acid open-hearth furnace, in two basic electric furnaces, and in a basic open-hearth furnace.

The thesis is divided into four parts, the first, second and fourth parts, each consisting of three chapters, and the third part of two chapters.

In Part I, after a chapter in which, *inter alia*, the conception of activity as introduced by G. N. Lewis (1901) is given, the author goes on in the second chapter to consider the activity of the elements dissolved in iron, namely, carbon, manganese, silicon, and oxygen. The third chapter is devoted to a consideration of the solubility of oxygen in iron, and to the reduction of iron oxide by hydrogen and carbon monoxide, and by carbon.

Part II of the thesis deals with the constitution of acid slags. The first chapter is concerned with slags containing only silica and oxide of iron, whilst in the second chapter those also containing oxide of manganese are considered. The reaction of acid slags forms the subject of the third chapter.

Part III is devoted to a consideration of basic slags, and in Part IV the writer deals with the equilibrium of silicon and with deoxidation, and in the final chapter sums up his conclusions.

Whilst the work is in many respects highly theoretical, it does appear to be based upon some carefully ascertained facts.—J. FERDINAND KAYSER.

F.I.A.T. REVIEW OF GERMAN SCIENCE, 1939–1946. "*Inorganic Chemistry.*" Parts II and III. Senior Author-Wilhelm Klemm. 8vo, pp. 179 + 275. Berlin, 1948: Office of Military Government for Germany, Field Information Agencies, Technical.

These parts continue the section on Special Inorganic Chemistry, dealing first with the halides and chalcogenides (compounds with oxygen, sulphur, selenium, and tellurium) of the alkali and alkaline-earth metals, of aluminium, and of the rare earth metals, lanthanum, neodymium, etc. The equivalent compounds of copper, silver, zinc, lead, gallium, and indium are next considered, followed by those of the transition elements. Studies of the preparation and properties of the hydroxides and hydrated oxides of most of the above metals come next, and a discussion of the preparation of amides, such as those of chromium and vanadium, nitrides, sub-nitrides, and double nitrides. A lengthier section then deals with phosphides, arsenides, antimonides, bismuthides, and the ternary combinations of these.

In a section on carbides and cyanamides is to be found a review of recent work on the preparation of tungsten, titanium, and boron carbides, and the 'hard-metals' containing these; the section on carbonyls, besides treating with the classic nickel and iron carbonyls, describes also the carbonyl sulphides and carbonyl halides of a number of other metals, and a special section deals with metal-nitrogen compounds. Complex metallo-organic compounds, such as dimethylamine-dimethyl aluminium are also described.

Part III begins with a long section on compounds of higher order, typical of which are borates, clay minerals, technical silicates, phosphates, and alums: research on the synthesis of such minerals as rutile, spinel, pyrites, and phlogopite is also described. More complex metallo-organic compounds than those previously described likewise receive treatment here, including those where metals themselves provide the linkages.

The conclusion of this part presents work on intermetallic systems; in this field, numerous fundamental measurements have been made, as of lattice parameter, transformation temperature, and solid solubility, in a range of systems, from praseodymium–gold to iron–uranium.

The standard of arrangement, layout, typesetting, and the reproduction of diagrams remains at a high level in these volumes.—J. P. S.

F.I.A.T. REVIEW OF GERMAN SCIENCE. "*Mineralogy.*" Senior Author, H. Steinmetz. 8vo, pp. 304. Berlin, 1948: Office of Military Government for Germany, Field Information Agencies, Technical.

The scope of this review embraces the examination of minerals by optical methods and the electron microscope, hardness, determination, geological aspects of mineralogy, separation of constituents of mineral masses, the synthesis of minerals, crystal chemistry, and crystallography. Whilst

most of the work reported is of specialized interest to the mineralogist, there are a few points of more general importance. Neuweiler has constructed a microscope with correcting lenses to counteract the astigmatism of the observer, which, he claims, markedly reduces visual fatigue. Wulff has prepared a monograph in which he discusses the selective advantages of "subjective" (visual) and "objective" (photometric) methods of colorimetry; and Klinger has described the advantages of the Leitz "Leifo" photometer, for use in metallurgical laboratories. Kuhlwein has obtained interesting information on the significance of the examination of coal between crossed Nicols. Electron microscopic studies have been carried out on Montmorillonite and bentonite; and it is suggested that German bentonite, by virtue of its finer structure, should be more suitable for use in boring than American bentonite. The chapter on the identification and separation of constituents of mineral aggregates deals mainly with laboratory techniques. Among the optical methods, the Leitz "Stereo-Compolux" microscope is interesting; this facilitates the recognition of coloured constituents by controlling the colour of the background. Other processes reviewed include pulverization, separation by heavy solutions (iridium tri-iodide (density 3·44 at 20° C.), has been used with success). Magnetic separation, flotation, air-blast separation, electrostatic separation, and "indirect analysis," that is to say, the estimation of the precise composition of a mineral by calculation when complete physical separation is impracticable. In the field of crystallography, various observers have analysed the crystal structures, and determined lattice constants of a few metals (Mg, Ca, Sr, Ba, and Ho) and a considerable number of binary, and a few ternary intermetallic compounds.

Inorganic compounds have also been extensively examined. Studies of crystallization phenomena include crystal growth in metals, and to a lesser extent, metallic corrosion. In conclusion, it should be repeated that the subjects mentioned above form only a very small selection from the contents of the review as a whole.—M. A. VERNON.

F.I.A.T. REVIEW OF GERMAN SCIENCE. "*Physics of Liquids and Gases.*" Senior Author, E. Kappler. 8vo, pp. 348. Berlin, 1948: Office of Military Government for Germany, Field Information Agencies, Technical.

It is inevitable that the researches reviewed under this heading, important as they are, should for the most part be of direct interest only to the pure physicist; and there is very little with which the metallurgist will be immediately concerned. One can, however, find a few isolated researches to which attention should be drawn. Schneider and others, have measured the partial vapour pressure of zinc over fluid aluminium–zinc alloys, and of magnesium over aluminium–magnesium. In the latter case the log P_i–$1/T$ curve was linear, and in the former a discontinuous curve. Vapour pressure of zinc and cadmium over alloys with copper, silver, and gold have also been measured. Hauffe and Wagner have studied the liquidus curves of a number of binary non-ferrous alloys. Walther has measured viscosities of coal tars between − 20° C. and 125° C., and Endell and his colleagues studied the effect of composition of acid blast-furnace slags on the η − T relationship, and suggested a means of calculating η for blast-furnace slags, both acid and basic, of known composition. A good deal of research has been carried out on the electric arc, some of it from the point of view of spectographic analysis, and Mannkopff has investigated the relationship of intensities of resonance lines of elements with their concentration. Hüttig has carried out an extensive series of investigations of the sintering process, using different metallic and metal-oxide powders, and Sauerwald has studied the effect of surface structure on sintering. Skaupy has worked on the production of hard metals. Kieffer and Hotop have compared the properties of sintered and cast metals, and found considerable differences; and Endell and von Ardenne have followed the sintering process in ceramic materials with a high-temperature electron microscope. In addition to the references to periodical literature, there is the customary list of important textbooks in the field covered.—M. A. VERNON.

GOETZEL, C. G. "*Treatise on Powder Metallurgy,*" Volume 1, "*Technology of Metal Powders and their Products.*" 8vo, pp. xxvii + 778. Illustrated: New York, 1949: Interscience Publishers, Inc.; London: Interscience Publishers, Ltd. (Price £4 10*s.*).

This is the first volume of three by the author who is Vice President and Director of Research of the Sintercast Corporation of America. It represents the most comprehensive and painstaking survey of the literature of powder metallurgy published to date. After two short introductory chapters dealing with the general principles of powder metallurgy and its historical development, the work commences with a chapter (45 pages) on methods of powder production. Although an adequate survey of the literature of the subject, this chapter is not sufficiently detailed to be of assistance to anyone proposing manufacturing metal powders. The physical characteristics of metal powders are described in some detail in 45 pages and Chapter 5 (31 pages) adequately surveys methods of testing powders. Chapter 6 (71 pages) repeats to some extent the earlier chapter on the manufacture of metal powder, but describes, in a way which would be of value to a newcomer to the subject, the physical properties and general commercial details and prices of currently available commercial metal powders. Oddly enough the author appears largely to have overlooked the information on the manufacture of metal powders available in various B.I.O.S. Reports. Chapter 7 (27 pages) deals with washing and drying, pulverization, sieving and blending, packing, shipment and storage, coating of metal powders, and mixing with non-metallic substances. These subjects are not considered in the same degree of detail as is used in other sections of the book.

The remainder of the book, beginning with Chapter 8, and covering all practical and theoretical aspects of pressing and sintering, is really excellent and is surveyed in the greatest detail. Chapter 8 (54 pages) considers the behaviour of powders under applied pressure and deals with the nature of the cohesive forces between powder particles, the effects of impurities, mechanical interlocking, the work of Balshin, and the more recent work of Unckel and of Wulff and his colleagues on the distribution of pressure in the die. In regard to the possibility of superficial melting during the pressing operation, the author, curiously, has not referred to the work of Bowden, and the author's description of his own experiments in attempting to disprove that melting takes place at contact points does not go sufficiently deeply into the matter nor carry much weight in view of the evidence from Bowden.

Chapters 9 (35 pages), 10 (33 pages), and 11 (40 pages), dealing respectively with the practical aspects of the pressing of powders, construction and manufacture of dies and punches, and design and operation of presses, are very well written, and will be of great assistance to potential manufacturers of powder-metallurgy parts.

In dealing with hot pressing the author is obviously very much at home, and gives the best and most detailed description of this so far inadequately developed aspect of powder metallurgy. Chapter 12 on this subject considers both the theoretical and practical aspects of hot pressing in 45 pages, and Chapter 13 (27 pages), reviews the design of various presses and die designs which have been used by various investigators into the subject of hot pressing. These two chapters are largely illustrated with work from the author's own laboratories and represents two of the most satisfactory chapters of the book.

Chapter 14 (75 pages) surveys in considerable detail the work of previous investigators and writers on the subject of principles of sintering. This chapter, which is a small book in itself, represents a very adequate survey of its subject and is handled with considerable clarity. The author has wisely refrained from making the present position concerning theoretical aspects of sintering even more obscure than it is by the introduction of any new theories of his own.

Chapter 15 (18 pages) and Chapter 16 (30 pages), describe methods of sintering and the construction and use of various types of sintering furnaces, and Chapter 17 (29 pages), reviews the theoretical and practical aspects of the use of various atmospheres for sintering. These chapters are admirable practical accounts well adapted to be studied by newcomers to powder metallurgy. The remaining chapters, 18, 19, and 20, amounting altogether to 51 pages,

consider in detail the use of various after-treatments such as re-sintering, hardening, quenching, shaping, cleaning, electroplating, and other surface coatings, impregnation and joining.

There are adequate author and subject indexes. The book is excellently printed on high quality paper, and considerably enhanced in value by illustration with a large number of excellent photographs and diagrams, particularly in the sections dealing with the practical aspects of the subject. The author's style is clear and concise, and makes easy reading. The book is particularly recommended to both the beginner and the expert in powder metallurgy.—W. D. JONES.

"*The Instrument Manual*, 1949." 4to, pp. vii + 548. Illustrated. London: United Trade Press, Ltd. (Price £3 10*s*.).

In producing this book, the publishers' professed aim has been "to provide in a convenient form general information of value to all concerned with industrial instruments," and it must be conceded that there can rarely, if ever, before have been published so comprehensive, concise, and up-to-date an account of the theory and practice of industrial measurements in a single volume. The work is divided into sections dealing with classes of measurements or instruments, and each section has been entrusted to an author, or authors, experts in that particular field. The bulk of the work is taken up by descriptive matter, giving definitions, theory underlying the methods of testing, and, where necessary, details of the construction and principles of operation of basic or representative instruments. This, for the most part, is lucid and adequate, although by no means of uniform excellence. To take a particular example, one would have liked to see a more complete account of the action of the electron microscope, to which instrument much space is rightly devoted. A good deal of useful quantitative data is included; again to quote two random examples, there are stress-strain diagrams for typical steels, and thermoelectric data for rare- and base-metal thermocouples. At the end of each section there is a well-selected bibiography of references to technical literature—an unexpected and welcome inclusion—and a buyers' guide, giving a list of British manufacturers of the types of instrument which have been described. The longest section (100 pages), deals comprehensively with automatic control. The authors have attempted to make each section complete and self-contained; this leads to a little overlapping, but this is deliberate and seems quite justifiable. There can be few modern measuring instruments, for either industrial or research purposes, which are not mentioned somewhere or other; but one or two electronic instrument, for example, the cathode-ray oscillograph, seem to be missing. Most of these, however, are used for research rather than routine measurements. The section on "Determination of Compositional Quality" describes, among other things, the mass spectrometer, X-ray diffraction and electric diffraction cameras, spectrographs and absorptiometers, and there is even a brief note on chromatography. A list of British patents, covering a period of a year, is included at the end as an indication of trend in instrument design. This seems to be of limited value, as it must inevitably be not only incomplete, but also out of date before publication. A collective directory of manufacturers, in alphabetical order, is also included. The book is well produced: illustrative photographs are moderately good, and line drawings excellent. There appear to be very few errors, although some curiosities are to be found in a line of chemical formulæ on pp. 235–238. Generally speaking, the publishers deserve congratulations on the excellence of their enterprise; in fact, the manual is so good that the reader should beware of the temptation to use it as a complete textbook, rather than a guide. By doing so he would be rendering a disservice alike to himself and to the authors.—M. A. VERNON.

KOENIGSBERGER, F. "*Design for Welding in Mechanical Engineering*." 8vo, pp. vii + 210. Illustrated. London, 1948: Longmans, Green and Co. (Price 18*s*.).

It has often been stated, with undoubted justification, that the application of welding to engineering structures calls for a special consideration of design principles if the full economic and technical advantages of the process are to be realized. While it is probably a fact that the background to the considerable advances made in this field of construction has been provided less by the development of theoretical principles than by the general attractiveness of welding as a manufacturing method, this statement is nonetheless true, and the need for a wider knowledge of the best design practices has long been recognized and proclaimed. For this reason Mr. Koenigsberger's book is a welcome contribution to the literature on the subject, particularly since it presents valuable guidance on certain aspects of welded construction that have hitherto not received adequate attention in this class of publication.

The author prefaces the book with an introductory outline of the technical and economic considerations that will generally dictate whether or not welding may be applied to advantage for a particular case. He also draws attention to the fact that for different materials (*i.e.*, cast iron and steel) the optimum shape of a structure will be different if the properties of stiffness and strength are used to their fullest extent. This important aspect of design is further developed in a later chapter which includes a number of graphs relating these factors for several structural elements, showing that advantage may be taken of the superior strength of mild steel without reducing rigidity.

The first chapter deals with the mechanical properties and weldability of steels commonly used for welded fabrication, and also the use of rolled sections and other forms of material. With regard to weldability, the author classifies materials into three groups according to the facility with which they can be welded. It appears that the author's point in so doing is to underline the desirability of using that material for which the least precautions are required; otherwise it would have been useful to have provided some further interpretation of these groups in terms of material specifications. The need for special rolled sections is discussed in the same chapter. There is much to commend this requirement, but in the selected case of special flange profiles for building up joists one would perhaps be justified in looking for experimental evidence of the technical superiority of this type of construction, particularly since research work on the continent has not verified a claim that is often made, *i.e.*, that the removal of the welded joint from the flange zone improves fatigue life.

In the following chapter details of arc and gas welded joints, and joints produced by the resistance welding processes, are discussed. A comprehensive analysis is made of the stress calculations for typical joint forms, and the problem of design for dynamic loading considered. The question of permissible stresses for fatigue conditions is, in the absence of authoritative recommendations and adequate research in this country, a difficult matter for the designer to establish. Most of the data available on the fatigue endurance of welded joint details are of American or Continental origin, some of which are quoted by the author, and it is open to doubt whether these figures could be accepted unreservedly as representative of British materials. In any case it is clear that there is considerable scope for further research work on these lines if more specific guidance is to be afforded on working fatigue stresses and the associated influence of design details.

The various examples included of the layout and design details of typical part assemblies and complete structures, together with appropriate stress calculations, form a most useful section of the book. These cover a wide field and illustrate the versatility and scope of the method in a manner that will be readily appreciated by the designer.

In conclusion the author considers the function of the drawing office. Probably not all will agree with him that a design drawing should carry with it foolproof instructions on, for example, the sequence and procedure of welding operations; in many cases this may not be attainable or even desirable if it is at variance with other works' systems that have been established and proved equally satisfactory. It is rightly stressed, however, that full details of weld sizes and material preparation and layout, with its attendant effects upon economy, must be adequately specified, and the responsibilities of the drawing office in this respect have not been overstated. With regard to the notes on inspection and the necessity for heat-treatment, these might, with advantage, have been included under

separate sections since they do not relate to the practice of laying out suitable drawings, apart from the obvious requirement of stating what should be applied.

There is no doubt that this book will be received with interest by engineers and students alike, and will prove of considerable benefit in providing a knowledge of the proper application of welding techniques. It is a thoughtful survey of an extensive subject, and will assuredly bear out the author's modestly expressed hope for his work.

R. P. NEWMAN.

MILTON, R. F., AND W. A. WATERS. "*Methods of Quantitative Micro-Analysis.*" 8vo, pp. vii + 599. Illustrated. London, 1949: Edward Arnold and Co. (Price 60*s.*).

This work is a co-operative effort by the co-editors together with G. Ingram, J. T. Stock, and K. M. Wilson, all of whom are skilled micro-analysts, and it may therefore be taken as an authoritative survey of modern methods. It is essentially of a practical nature; that is to say, it is inteaded to meet the requirements of the practical analyst, well versed in routine methods, who may be called upon to undertake work in this specialized field. The field covered comprises gravimetric, volumetric, colorimetric, electrochemical, and gasometric methods. Spectrography has been deliberately excluded on the grounds that its scope is too wide for adequate treatment in the present volume, and that it requires expensive apparatus not normally available to the routine analyst; it is claimed that most, or all, of the methods described can be carried out with the normal resources of the ordinary analytical laboratory. Although a considerable proportion of the work is concerned specifically with organic and biological microanalysis, with which the metallurgical analysts will not generally be concerned, nevertheless, he will find most of the technique of interest, and some at least, of direct application.

The general plan adopted by the authors is roughly the same in each of the main sections. Where necessary, the basic theory of the method is briefly outlined; the specialized apparatus and technique are described; a detailed account is given of a few illustrative practical analyses, and finally there is a tabular summary of elements or substances which can be estimated by the particular method, giving brief working details, and a reference to the book or periodical literature from which the example is taken.

A few points of special interest are worth noting. The section on gravimetric methods includes notes on special organic reagents for the analysis of metals, and a table of methods for the estimation of metals, giving the selected method for each metal. In the next section (volumetric) there is a useful list of some 24 indicators for acid-alkali titration, giving the method of preparation and *p*H range of each. The section on colorimetric (which includes detailed accounts of nephelometric and fluorimetry, and a brief reference to chromatography), has summarized details taken from Vaughan's paper on metallurgical analysis; and, of course, there are numerous applications of electrochemical techniques in the metallurgical field.

It will be seen, from what has been said, that the treatment of the subject is clear and logical, and the coverage remarkably extensive; and the book can be confidently recommended to the working analyst.—M. A. VERNON.

THEWS, E. R. "*Metallurgische Verarbeitung von Altmetallen und Rückständen.*" Band 1. "*Altweissmetalle.*" 8vo, pp. 359. Munich, 1948. Carl Hanser Verlag. (Price 22.50 DM.).

This book deals with a subject which always has been important throughout the world, and which must be of overwhelming importance in Germany at present, *viz.*: the recovery of scrap metals and residues. The author deals thoroughly with the subject in a publication which is divided into four main sections, comprising 15 chapters in all.

Section A, comprising two chapters, deals with the economic side of the subject and with the different forms in which material is available. Chapter 3 covers transport, breaking up, melting, baling, briquetting, crushing of turnings, handling of residues, storing and sorting. Chapters 4 and 5 are devoted to a consideration of the treatment of zinc and lead residues respectively. White metal alloys and the residues which result from the use of white metal bearings, solder, type metal, etc., are covered by Chapter 6. Chapter 7 is devoted to a consideration of the handling of metallic dust and *inter alia* deals with the use of slacked lime, with or without the addition of Portland cement, for the production of briquettes. Chapter 8 deals with the choice and technicalities of fluxes. In Chapter 9 the author describes the poling of metals and alloys by forcing steam through them when in the molten state, a process which he points out has superseded the poling of metals with green wood.

The whole of section C, comprising four chapters, is devoted to a consideration of melting furnaces and heating media. The book concludes with a chapter of useful tables and a subject index.

This is a well written book and its publication is most opportune.—J. FERDINAND KAYSER.

NEW PUBLICATIONS

AMERICAN INSTITUTE OF MINING AND METALLURGICAL ENGINEERS. "*Blast Furnace, Coke Oven and Raw Materials Committee of the Iron and Steel Division.*" Proceedings, vol. 7, Pittsburgh Meeting, Apr. 12–14, 1948. 8vo. pp. 178. Illustrated. New York, 1949: The Institute.

AMERICAN WELDING SOCIETY. "*Standard Welding Terms and their Definitions.*" 8vo, pp. 50. New York, 1949: The Society. (Price $1.00).

AMERICAN WELDING SOCIETY. "*Standard Master Chart of Welding Processes and Process Charts.*" New York, 1949. The Society. (Price 35 cents.).

BRITISH STANDARDS INSTITUTION. BS 1548: 1949. "*Analysed Samples for Metallurgical Analysis.*" 8vo, pp. 6. London: The Institution.

DAVIES, O. L. "*Statistical Methods in Research and Production with Special Reference to the Chemical Industry.*" Second Edition, Revised. 8vo, pp. xi + 292. London, 1949: Oliver and Boyd. (Price 28*s.*).

FILASIEWICZ, K. "*Walcownictwo.*" Pp. 300. Illustrated. Gliwice, 1947: Nakladem Komisji Wydawniczej Bratniej Pomocy Studentow Politechniki Slaskiej.

HOTTEL, H. C., WILLIAMS, G. C., and C. N. SATTERFIELD. "*Thermodynamic Charts for Combustion Engineers.*" Pp. 62. New York, 1949: John Wiley and Sons. (Price $2.60).

HÖVEL, T. "*Sintereisen. Seine Herstellung nebst gesammelten Erfahrungen.*" 8vo, pp. vi + 69. Illustrated. Brunswick, 1948: Vieweg und Sohn. (Price 4.50 DM.).

INSTITUTE OF FUEL. "*Report of the Conference on Pulverised Fuel, held at Harrogate from June 2 to June 6, 1947.*" 8vo, pp. 914–1084. London, 1948: The Institute.

IYER, V. GOPALAM. "*Metallurgical Analysis.*" 2nd Edition, pp. 612. Benares, 1948: Hindu University. (Price 15 Rs.).

MÜLLER, R. W. "*Der Formereibetrieb. Aus der Praxis—für die Praxis.*" 8vo, pp. iv + 187. Illustrated. Halle (Saale) 1948: W. Knapp. (Price 6.80 DM.).

NAUMANN, F. "*Praktische Form und Kernentlüftung.*" (Bd 3 der Schriftenreihe: Bücher der Giesserei-Praxis). Pp. 91. Illustrated. Berlin, 1949: Schiele und Schön.

PELOU, M. "*Les Aciers de Fabrication Française.*" 4ème Edition. Paris, 1948: Science et Industrie. (Price 2500 francs).

PLUMLEY, S. "*Oxyacetylene Welding and Cutting.*" A Course of Instruction. Revised and Rewritten by T. B. Jefferson. Fourth Edition, 4to, pp. 1–356. Illustrated. New York and London, 1949: McGraw-Hill Book Co., Inc. (Price 39*s.*).

WINNING, J. "*Alloy Steels: Their Properties and Industrial Application.*" (Mechanical World Monographs No. 49). Manchester: Emmott and Co., Ltd. (Price 2*s.* 6*d.*).

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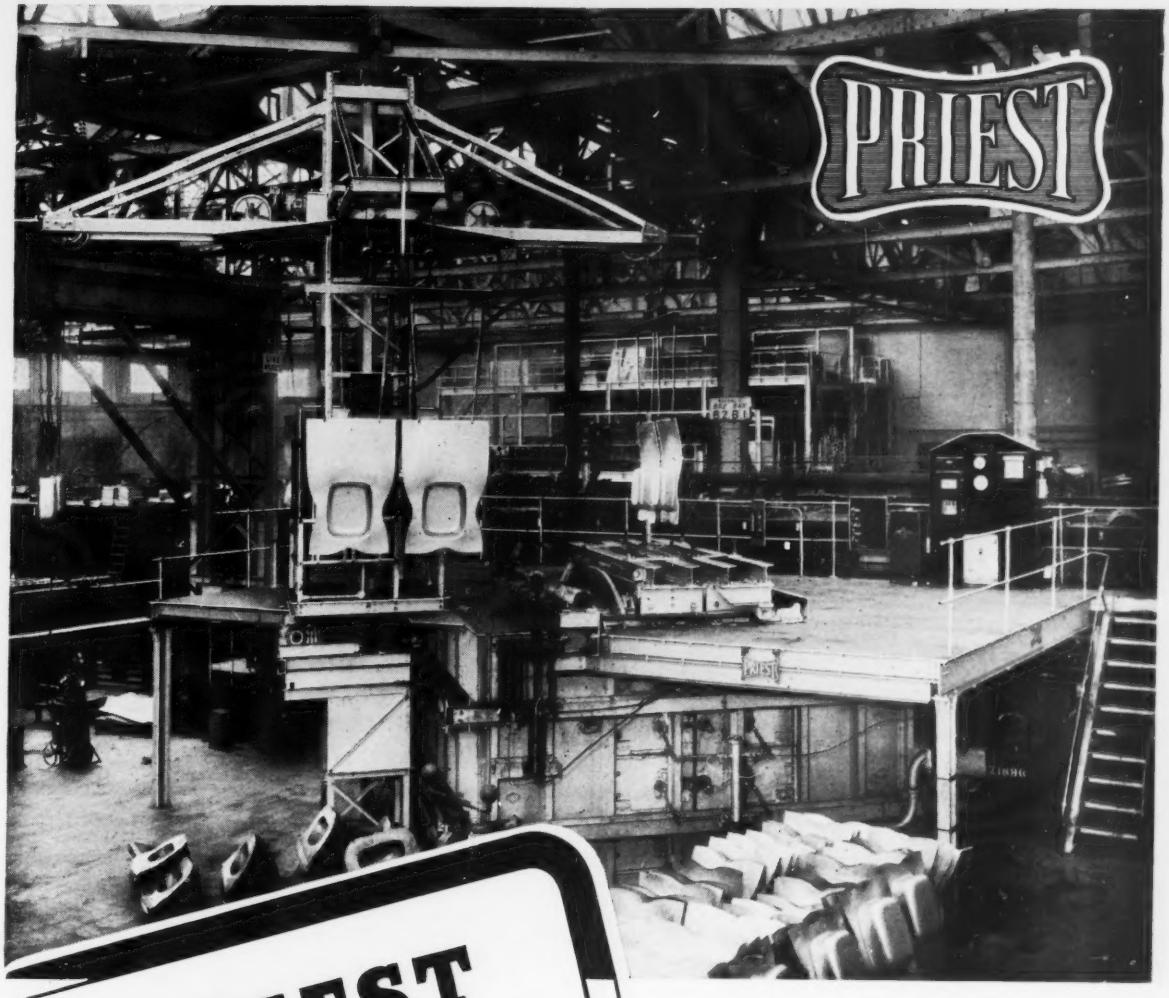

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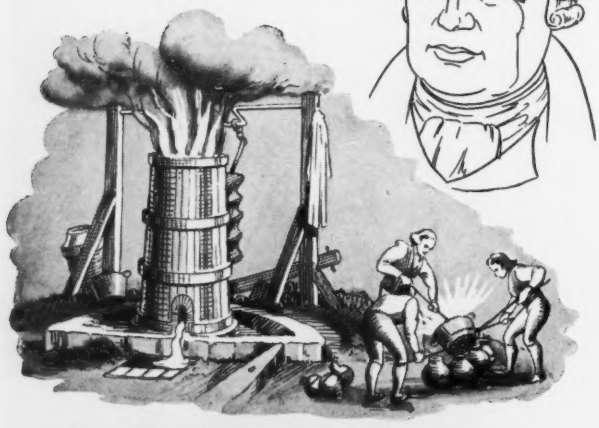

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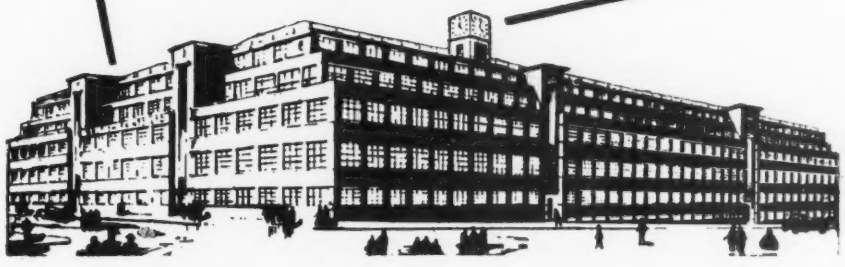

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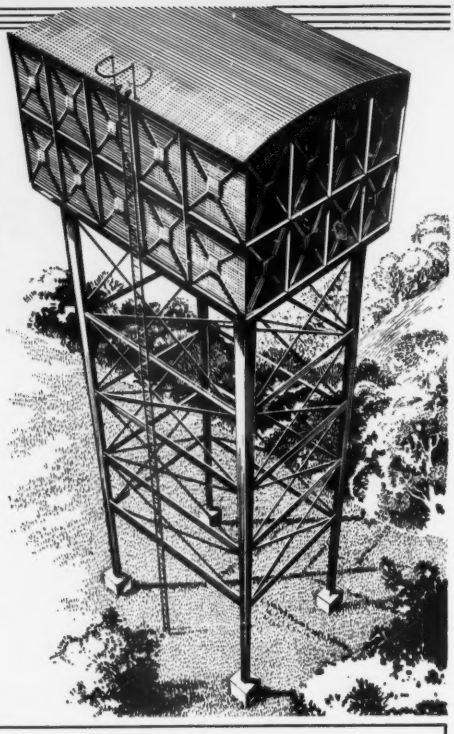

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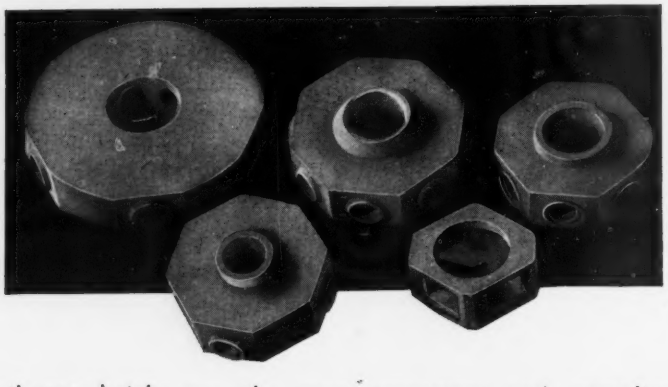

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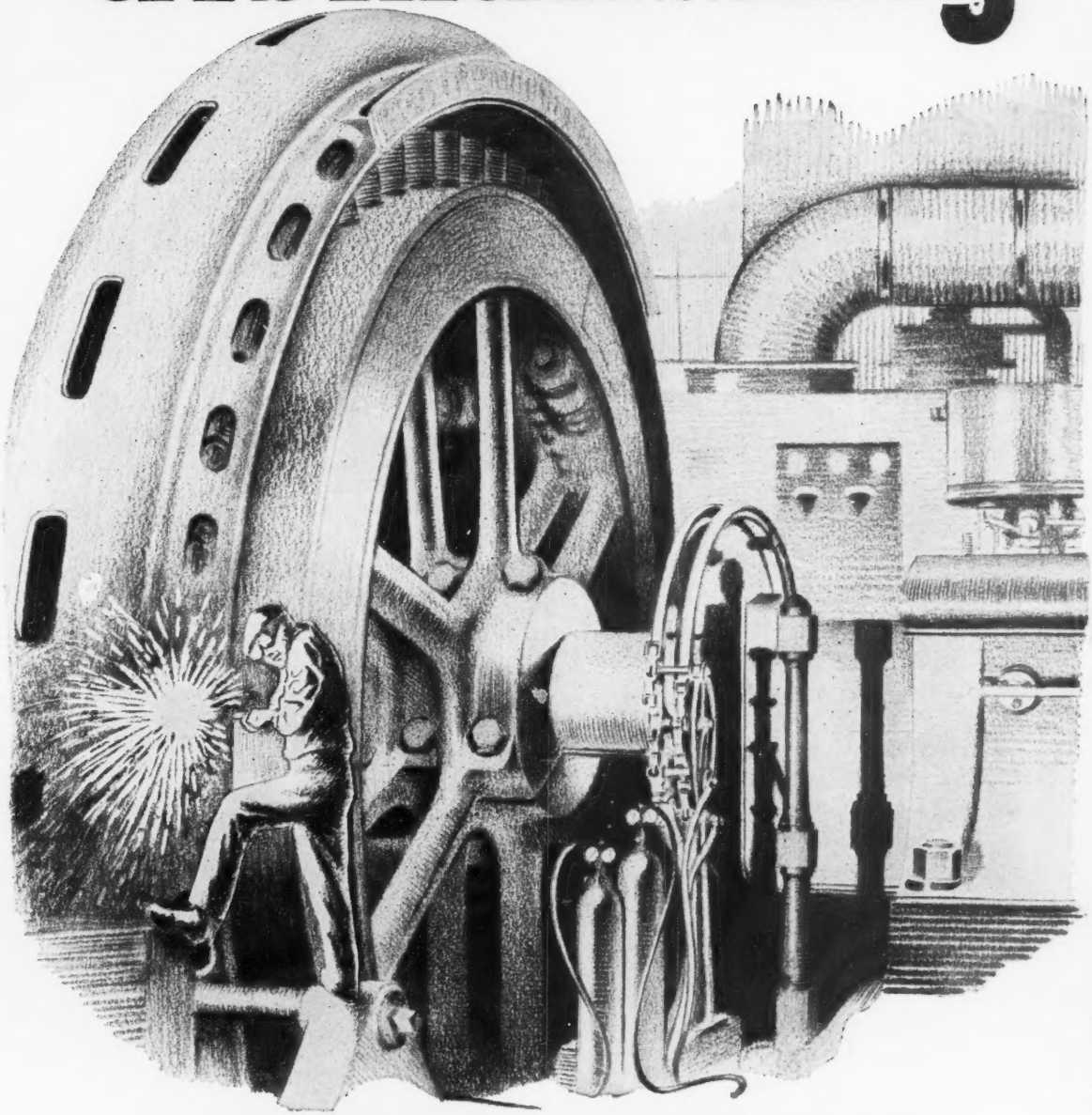

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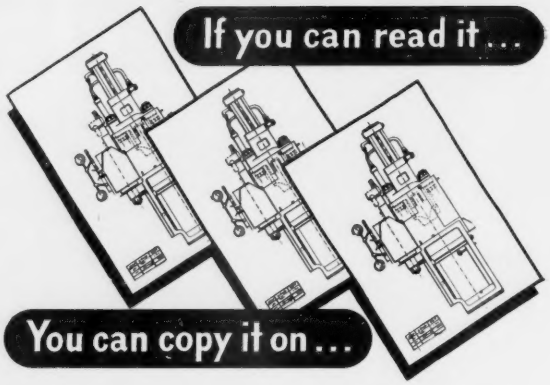

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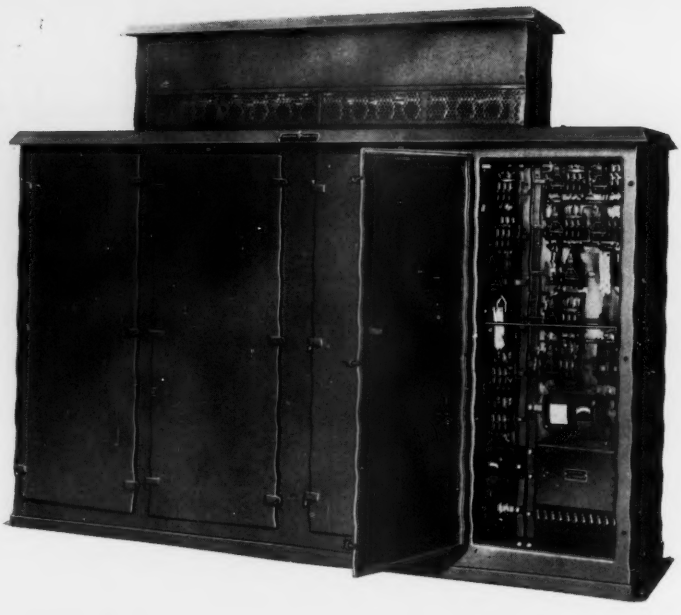

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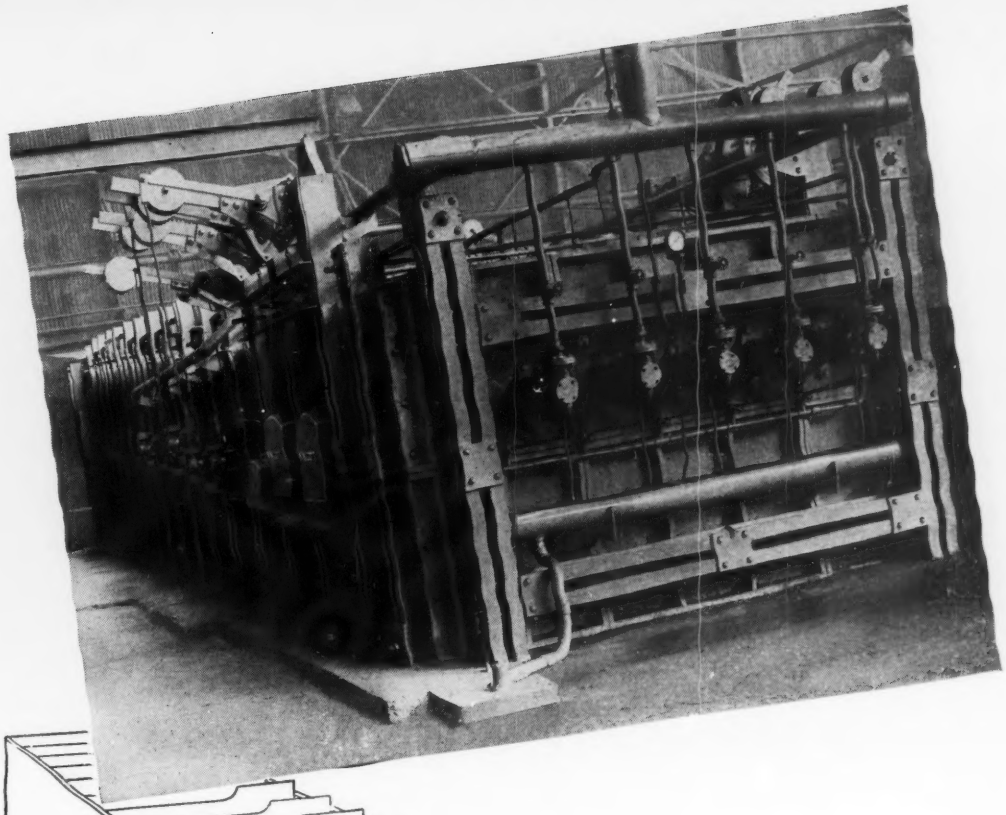

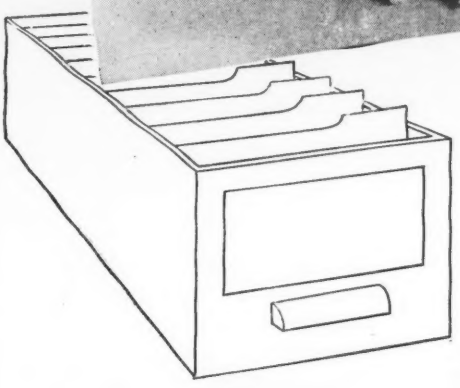

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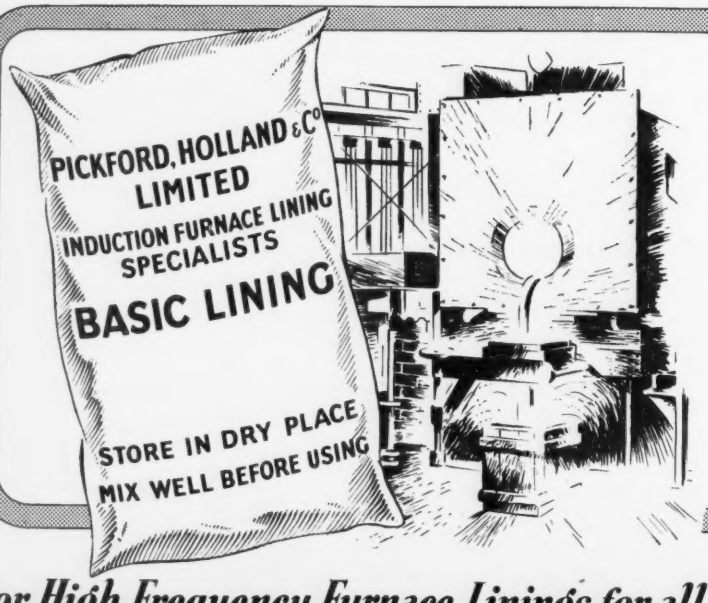

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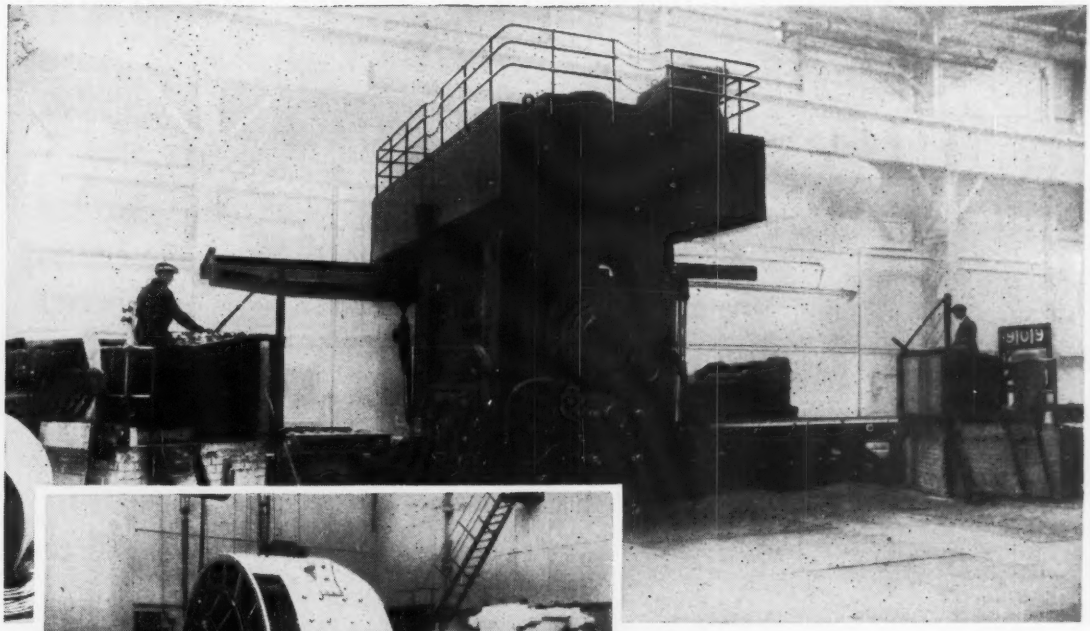

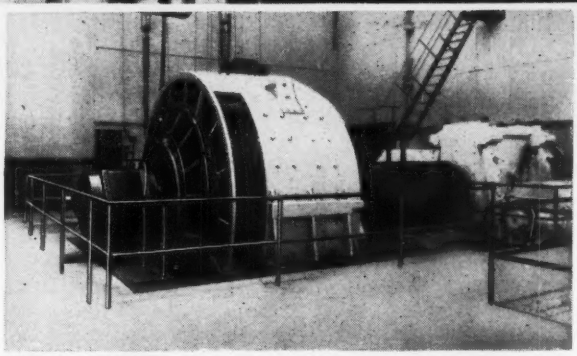

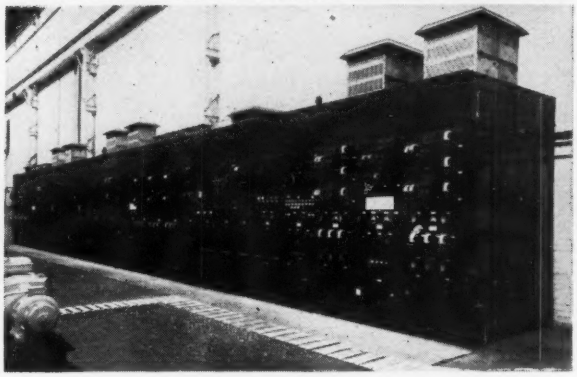

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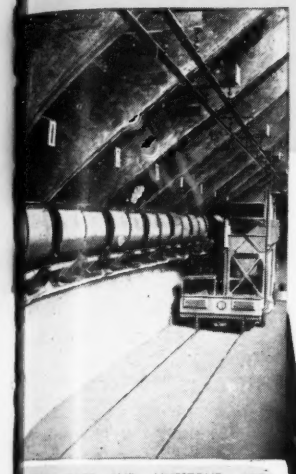

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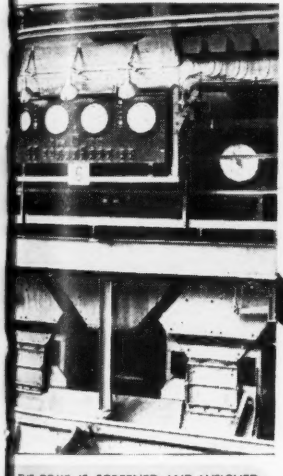

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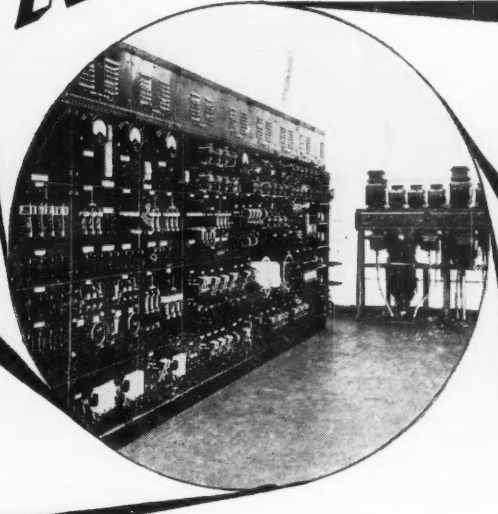

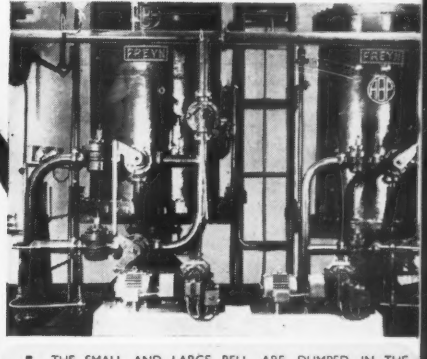

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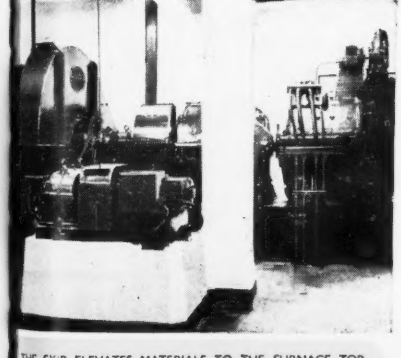
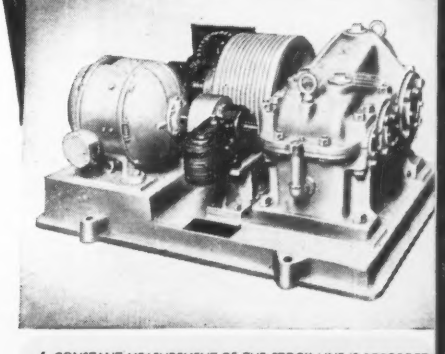


THE SKIP ELEVATES MATERIALS TO THE FURNACE TOP.

7. THE WHOLE IS INGENIOUSLY SEQUENCED AND INTERLOCKED AT THE CENTRAL CONTROL PANEL OPERATED FROM THE PANEL SEEN IN FIG. 2.



6. CONSTANT MEASUREMENT OF THE STOCK LINE IS RECORDED

ABP

ASHMORE, BENSON, PEASE & CO., LTD.

STOCKTON-ON-TEES ENGLAND

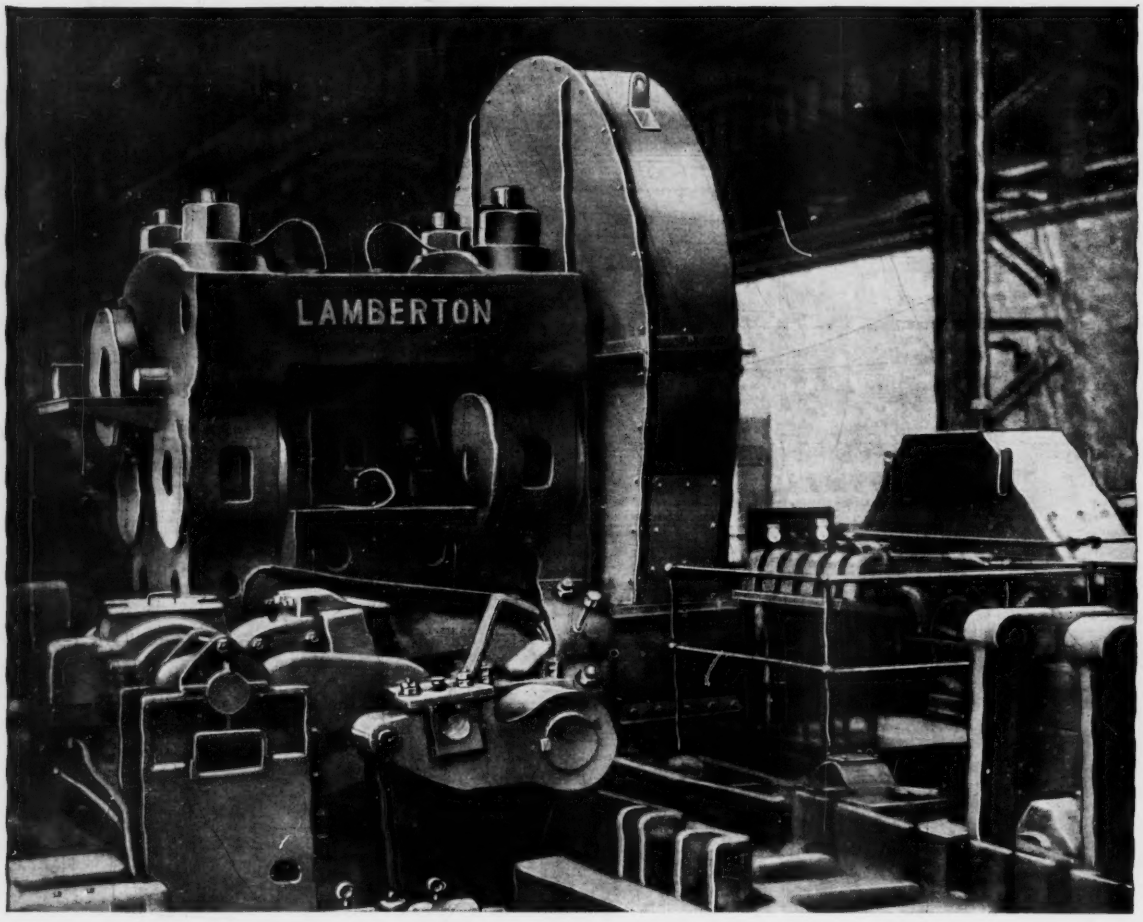
AND LONDON, AUSTRALIA, CANADA, INDIA, SOUTH AFRICA

A-BPC

LAMBERTON

Rolling Mill Plant Manufacturers

COATBRIDGE - SCOTLAND



HOT BLOOM SHEAR

1200 TON LOAD - TWIN MOTOR DRIVE

3931 45m

1949